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Specifying, Analyzing, Integrating Mobile Apps and Location Sensors as part of Cyber-Physical Systems in the Classroom Environment

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To you as a reader

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¹Literally, particularly in presentations and in git repositories.

ABSTRACT

Cyber-Physical Systems (CPS) are characterized as complex systems usually networked, composed of several heterogeneous components that make the connection between events in the physical environment with computation. We can observe that this kind of systems is increasingly used in different areas such as automotive facilities, construction (civil engineering), health care and energy industry, providing a service or activity which depends on the interaction with users and the physical environment in which they are installed.

Nowadays, in the educational context, the process of control and monitor of evaluation activities is conducted in a non-automated way by lecturers. This control is performed before, during and after the beginning of the evaluation activity, and include logistical processes such as classroom reservation, distribution of students per classroom, attendance record or fraud control. However, in an environment involving a large number of students, the execution of these tasks becomes difficult to perform efficiently and safely, requiring innovative techniques or assistance tools.

In this work, the creation/design of a cyber-physical system through a modeling approach is proposed, aiming to help teachers to control and monitor evaluation activities. Based on a systematic literature study, we claim that there are no studies presenting the modeling of cyber-physical systems in an educational context, enhancing the interest of the proposed case study.

In this document, we show how we used a framework named ModelicaML to model this system during the design phase. Also, this framework will offer a simulation component to simulate the behavior of the prescribed system. On the side of the hardware architecture, for the purpose of identifying the valid seats for the specific students in-class during the examination period, an indoor location system will be used, allowing to blueprint the physical layout of the room and globally manage the activity workflow.

We finish this work by showing with empirical studies the gains of our solution when compared to the traditional method.

Keywords: Monitorization of Evaluation Activities, Modeling Cyber-Physical Systems, Indoor Positioning Systems, Location Sensors, ModelicaML, Estimate, BLE Beacons

RESUMO

Os sistemas ciber-físicos caracterizam-se por serem sistemas complexos habitualmente interligados, compostos por vários subsistemas, que ligam eventos do ambiente físico aos elementos computacionais. Estes sistemas são cada vez mais usados em diversas áreas tais como na indústria automóvel, civil, energética ou da saúde e fornecem um serviço ou uma atividade que depende da interação com os utilizadores e com o ambiente físico em que se encontram instalados.

Atualmente no contexto da educação, o processo de controlo das provas de avaliação é realizado de forma não automatizada pelos docentes responsáveis. Este controlo, é realizado antes, durante e após as provas de avaliação, e inclui processos logísticos como a reserva de salas, distribuição dos alunos, registo de presenças ou controlo de fraude. Contudo, num ambiente onde o número de alunos é elevado, a realização destas tarefas torna-se difícil de ser executada de forma eficiente e segura, requerendo técnicas ou ferramentas inovadoras.

Neste trabalho, será proposto a criação/conceção de um sistema ciber-físico através de uma abordagem de modelação com a capacidade de ajudar os docentes a realizar o controlo das provas de avaliação. Baseado nos resultados provenientes da pesquisa efetuada, não foram encontrados estudos que sugiram a modelação de sistemas ciber-físicos no contexto da educação, tornando interessante o caso de estudo proposto.

Para modelar este sistema, recorrer-se-á à ferramenta ModelicaML que permite modelar o sistema proposto e oferece uma componente de simulação do sistema. De forma a localizar os lugares válidos para o aluno realizar a prova de avaliação, será implementado um sistema de localização que permite virtualizar o mapa da sala e gerir a atividade da mesma.

Para concluir este trabalho, demonstramos através de estudos empíricos os ganhos da nossa solução quando comparado com o método tradicional.

Palavras-chave: Controlo de Provas de Avaliação, Modelação de Sistemas Ciber-Físicos, Sistemas de Posicionamento Interior, Sensores de Localização, ModelicaML, Estimote, *BLE Beacons*

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ACRONYMS

BIM Building Information Model.

BLE Bluetooth Low Energy.

CPS Cyber-Physical System.

GPS Global Positioning System.

GSM Global System for Mobile Communication.

IoT Internet of Things.

IPS Indoor Positioning System.

OMG Object Management Group.

QA Quality Assessment.

RQ Research Question.

SLR Systematic Literature Review.

Tx Transmission Power.

UML Unified Modeling Language.

INTRODUCTION

This chapter contains a brief introduction to the work developed in this dissertation. It starts by introducing a short description of the context and motivation behind this thesis followed by the problem statement, expected goals and main contributions. This chapter ends presenting the global structure of this document.

1.1 Context and Description

With the widespread of technology around the physical environment, computers are now everywhere. There are several different types of computers, ones are more powerful and sophisticated than others, used to control engines, traffic lights, home appliances and other similar varieties of systems [Lee+08]. These kinds of computers are called *embedded systems*.

However, these systems have limited resources and do not interact with the physical processes in the environment of the hardware, creating a major challenge in designs.

Along these lines, **CPSs** start to emerge, filling up the gap between the computational parts and physical processes. The definition of these systems relies on a set of layers responsible for collecting data, communicate between systems and actuate accordingly to the logic implemented in the software.

For instance, **CPSs** have been used lately in the context area of *smart cities*¹, providing a path for information flow between subsystems implemented in different sectors. It is also worth mentioning that **CPSs** offer computational processes from a small form-factor low-cost device with low-energy consumption [Raj+10].

¹City that uses digital technologies to intensify the quality of life and engage more interaction with citizens in several sectors, including energy, health care and other key areas [JTC14].

1.2 Motivation

Designing and building a vast system can face some challenging aspects. To create a CPS, we need to process three key stages: *modeling*, *design*, and *analysis*. The modeling stage is the most crucial and requires the system's engineer to perform a model that emulates the properties of the system. However, we may want to build a system that requires remodeling to the context environment in a dynamic way, preventing the designer to adopt a bottom-up approach to developing a system build on top of different subsystems.

Following this particular mindset, with the usage of hardwiring approaches, the system must be adapted if the requirements are changed. An approach that does not rely on technological dependencies of the system must be used to avoid the drawback of hardwiring practices.

Particularly in the educational system case, there are management tasks such as schedule distribution or back office processes using IT solutions to assist and help faculty members to carry them out [Del; Ibm]. However, plenty of tasks are still not supported with proper technological solutions and could be improved by developing a particular solution to support their achievement. For example, managing logistics inside and outside a classroom during the evaluation activity can be a difficult task to perform. Such kind of tasks sometimes involves a significant number of students, making it difficult to execute and have an efficient management in such environments.

This way, a CPS could be designed to perform a set of tasks aimed to improve efficiency and productivity during evaluation activities in a classroom environment. It is important to note that there are no current applications in this area that take advantage of CPS's approach. Among other possibilities, the proposed system can help on tasks such as monitoring attendance and authenticity to avoid fraud, entrance path optimization during the beginning of the activity and monitoring environmental quality during execution of the evaluation activity such as noise levels or temperature.

1.3 Problem Statement and Final Goals

Based on the problems identifies in section 1.2, we are interested in solving the problem of controlling and monitoring the classroom environment during evaluation activities. Our system intends to automate and assist the assessment activity within the classroom environment, knowing beforehand that the variability of the room physical characteristics is wide. Certain aspects, such as different room sizes and their arrangement, lead to different student locations in diverse activities, making desirable that the proposed solution should be highly adaptable to different environments.

This system has CPS's characteristics as will be discussed later, particularly concerning the interaction with the physical environment, control layers, sensors, actuator devices and communication with other systems.

We believe that CPSs are an innovative approach that allows us to solve this problem in an abstract approach and that does not depend on the technology used in the solution. Hence, since technology does evolve in a fast way, the ambition of this research is to have a modeling approach for this CPS applied for the classroom environment, using state-of-the-art techniques that do not rely on technological choices.

Through this modeling approach and since the proposed system has an impact in the evaluation activity, it is not possible to perform tests and the system validation at runtime, as these may interfere with the assessment performance. Also, modeling brings the benefit of simulation, allowing a rigorous reasoning about the operation of the system, before it is implemented and deployed.

Concerning the ideas presented, we suppose to have an Indoor Positioning System (IPS) with good location abilities that allow us to solve this problem.

Therefore, the main research question we intend to study is **how to conceive and implement a CPS using a modeling approach for a classroom environment support**.

Regarding this research question, we will model the CPS described that will allow us to obtain a solution to the identified problem.

1.4 Main Contributions

The outcome result from this investigation contributed with:

- A study about state of the art techniques for modeling CPSs and locate targets inside a building using an IPS;
- A CPS solution composed of hardware and software designed to help faculty members during evaluation activities;
- Validation using real use case scenarios to analyze and compare the expected behavior of the CPS and the actual behavior;

1.5 Document Structure

Besides this chapter, the remaining document is structured in the following way:

- **Chapter 2 – Background:** This chapter presents important concepts to understand the work proposed in this thesis. It begins by describing the concept of CPSs and its components, ending with a detailed process description of a typical in-class evaluation scenario.
- **Chapter 3 – Case Study:** This chapter contains a detailed description of the proposed case study. It starts with a set of requirements that must be fulfilled followed by an explanation of the architecture and the relationship between several components.

- **Chapter 4 – A Systematic Literature Review:** This chapter presents a brief research and study about previous works related to the proposed approach of this thesis. It begins by describing the research process in detail, followed by a presentation of the results. Finally, a brief discussion about the selected results is made followed by a summary of relevant information to retain from this chapter.
- **Chapter 5 – Related Work:** This chapter contains a detailed analysis of the results selected in the previous chapter. For each research question, a comparison is made between the various available solutions, ending each section with a detailed analysis of the chosen solution.
- **Chapter 6 – Conceptualization and Implementation:** This chapter presents a detailed description of the prototype developed in this dissertation. It begins by introducing the modeling of the system through the requirements engineering processes, followed by the implementation details of the remaining subsystems that complement the proposed solution.
- **Chapter 7 – Evaluation:** This chapter contains a detailed analysis of the results obtained using the system developed in a real case study. It begins by describing the methodology used to perform the system's evaluation followed by a discussion and comparison of the performance results obtained.
- **Chapter 8 – Conclusions:** This chapter presents a summary of the work developed and presented in this dissertation. To conclude, suggestions for the future work are presented.

BACKGROUND

This chapter presents important concepts to understand the work proposed in this thesis. It begins by describing the concept of CPSs and its components, ending with a detailed process description of a typical in-class evaluation scenario.

2.1 Cyber-Physical Systems

For the purpose of the work described in this document, we will start by defining what a CPS is and which systems can be considered cyber-physicals.

Lee and Seshia, in [LS11], established that a CPS must represent computational and physical properties defined in the following activities:

- **Physical Layer** – CPSs integrate computation with physical processes. This types of processes are not connected with the digital world and can include elements as mechanical systems or humans. Moreover, physical processes can be composed by many concurrent activities, arising challenges in the modeling stage [Der+12a].
- **Sensors and Actuators Layer** – CPSs use several sensors to monitor and collect information about the physical environment and use actuators to interact with the physical world, coupling the cyber world with the physical layer.
- **Control Layer** – CPSs provides control mechanisms using several components and logic decisions. The system must read the measures provided from input sensors, process the data and determine the correct behavior to change the actual state. An output action should be reflected using the actuators to transform the physical environment. Such systems are called **closed-loop systems** [Hu13], and this cycle is called **feedback control loop** [LS11]. As a consequence of condition changes in the environment, the control approach enforced must have an adaptive and predictive

behavior, responding to changing conditions and anticipating transformations in the physical processes [Shi+11]. Therefore, the system inherits the capability to reorganize and reconfigure dynamically.

- **Network Layer** – CPSs can exchange information between systems, communicate through the Internet or connect with other devices and sensors using network fabrics that provide communication channels, such as wired or wireless networks, Bluetooth, Global System for Mobile Communications (GSMs), etc. [Hu13].

Abstracting the granularity detail in CPS's concept, the control layer and sensors/actuators layer structure the **platform layer**. A system may have one or more platform, connected through a network fabric that allows data transfer. Fig. 2.1 shows a simplified layout of a CPS.

To summarize, the **cyber** framework includes control, sensors and actuators layers and the **physical** framework includes physical objects and processes. Finally, the network layer links both frameworks.

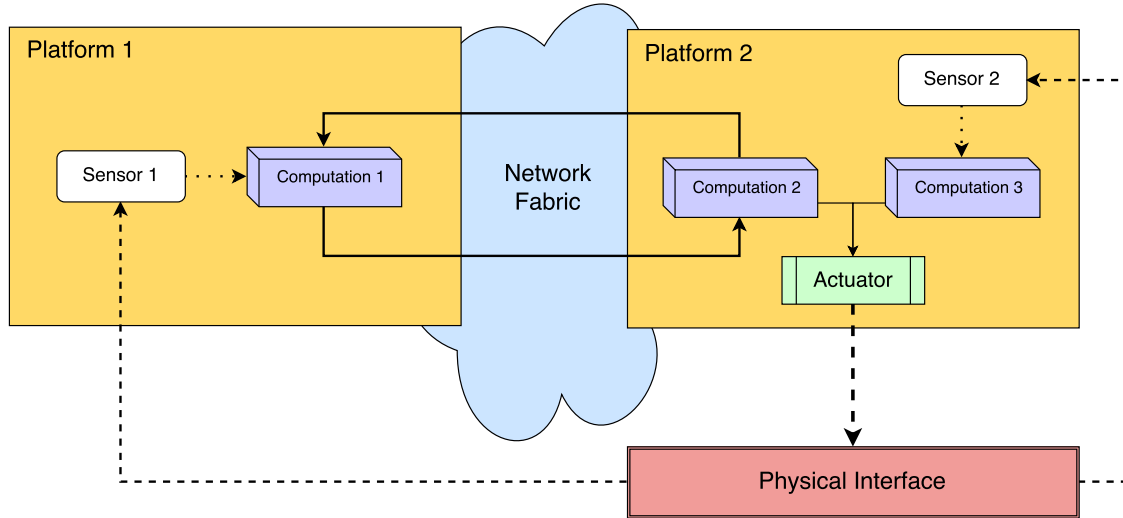


Figure 2.1: Simplified layout of a CPS

An example of a well-known CPS is the Anti-Lock Braking System (ABS) that equips many transportation vehicles [Ant14; Mar10].

This system is composed by a set of sensors, actuators, and control units interconnected with each other and it is responsible for preventing the wheels from locking up and skid while braking a vehicle.

The system operation initially begins with a user interaction, by placing the foot on the brake pedal in order to trigger the vehicle braking system. Consequently, a set of sensors distributed by each wheel of the vehicle collect the information about the angular speed of rotation, and then sends it back to the ABS control unit.

In this unit, based in the control instructions implemented, the behavior that will be expressed through the brake pads will be determined to be applied to each wheel.

Each actuator will have an independent behavior according to the response of the ABS control unit, thus preventing the wheels from locking up [Bos].

Fig. 2.2 presents and describes the operation of an Anti-Lock Braking System (ABS).

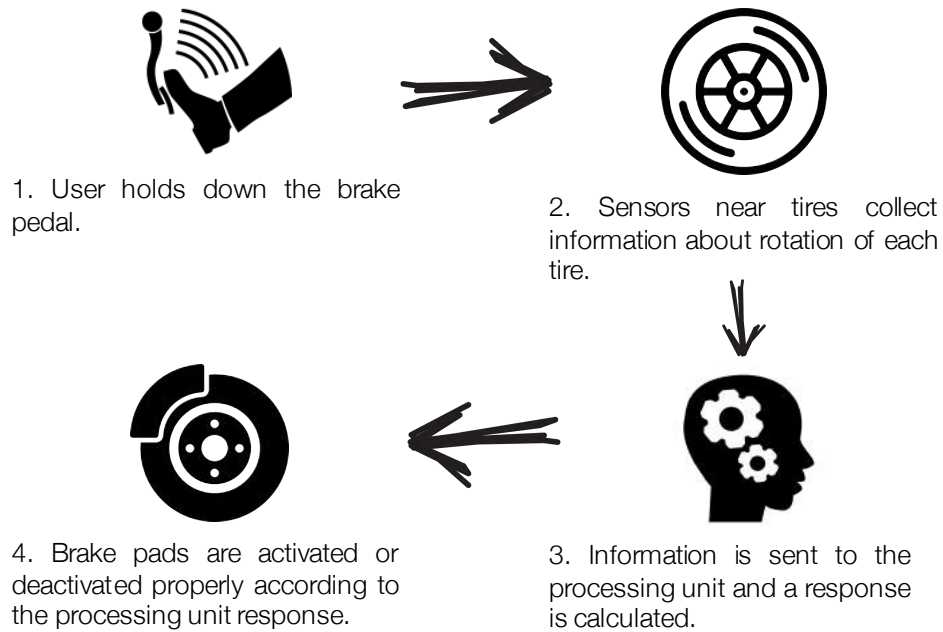


Figure 2.2: CPS example of an Anti-Lock Braking System (ABS)

2.2 Typical In-Class Examination Scenarios

Nowadays the control and management of the student's in-class examination procedures is mostly done manually¹ by the faculty member. This is true at FCT/UNL and generally in the rest of the universities and teaching institutions in Portugal during intermediate or final exams.

Through the Faculty's Information Systems, the student is usually informed about the date, starting times and rooms where the event will take place. Most of the times several rooms have to be used due to the relatively large number of students enrolled, since it may not be possible to fit all the students in a single lecture room.

A typical scenario is that before starting the exam, each student must wait in the doorway of one of the classrooms until he/she is allowed to get inside. Sometimes, attendance control must be done to check whether if the student is registered for the specific evaluation activity.

After the entrance, students have to sit in a place of their choice carrying their student's card to be verified later.

Then, the faculty member checks each student enrolled in the activity, marking his/her position in the map² with the classroom's layout. For each student, their student number and their position within the classroom should be recorded. Also, the faculty member may interrupt the student to validate and sign the recorded information, which is a laborious task and can potentially lead to the situation where the student suffers from a loss of concentration and break the line of thought.

At the end of the exam, each student might be asked to register the number of exam resolution sheets delivered and can be required once again to sign and validate the recorded information (confirming that he/she has finished and handed out the exam). After this, the student can leave the room.

Fig. 2.3 illustrates the process workflow described of a typical in-class examination activity.

¹Without automation.

²For in-place and later fraud control.

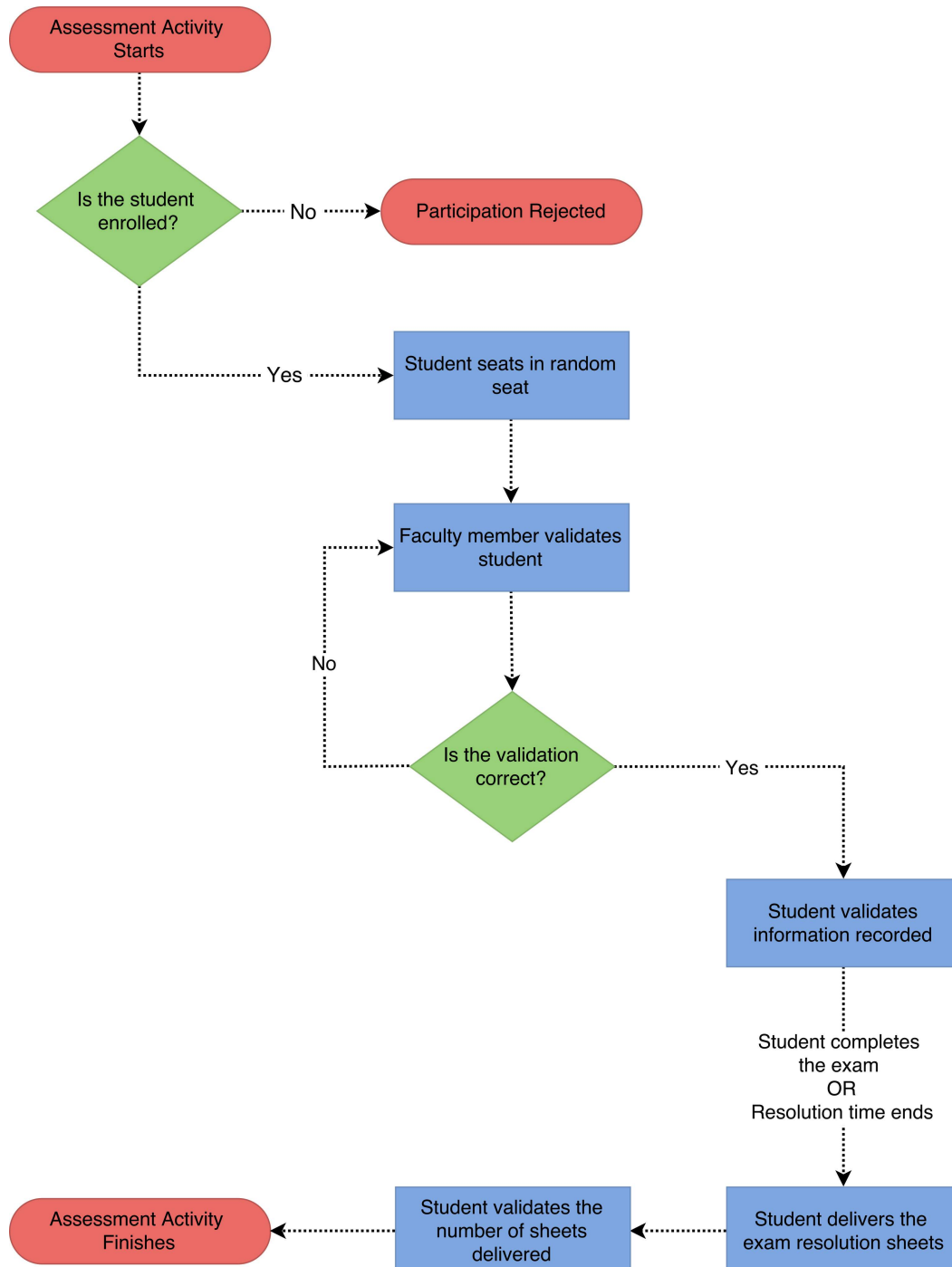


Figure 2.3: Typical in-class examination workflow

CASE STUDY

This chapter contains a detailed description of the proposed case study. It starts with a set of requirements that must be fulfilled followed by an explanation of the architecture and the relationship between several components.

3.1 Requirements of the Proposed Case Study

In order to validate this investigation, it is going to be used an innovative, realistic and comparable case study for education context. The proposed system aims to assist faculty members during evaluation activities in a classroom environment, providing authentication methods, access control, and logistics management.

Owing to the fact that most classrooms are different and some activities require changing the layout of the room, the system must be adaptive since we want to avoid fingerprinting each physical environment. Also, since a [Global Positioning System \(GPS\)](#) loose significant power indoors due to the signal attenuation caused by construction materials [Kjæ+10], an [IPS](#) is going to be used for blueprinting the room and each individual seat. The faculty member responsible for the evaluation activity should mark all valid seats with a mobile phone beforehand.

Furthermore, students have to check-in as they arrive in order to arbitrate a seat position to perform the evaluation activity.

During the activity execution, each student should place their institution ID cards besides themselves with the purpose of being authenticated as their claiming to be and check if they are in the right place.

Finally, each student has to be checked out at the time of exam delivery to complete the activity.

3.2 Architecture

Regarding the key aspects discussed in section 2.1, the proposed CPS has the following architecture:

- **Physical Layer** – There are two major physical processes that will interact with our system: The marking of valid seats by the faculty member and the authentication/-validation of students enrolled in the evaluation activity. During the marking of places, the system will have to save the coordinate inside the room of each place and after finishing the marking activity, the system will have to create a virtual map of the valid places. Later, for each student who check-in, the system will have to assign a place to hold the activity.
- **Sensors and Actuators Layer** – Our system is composed by two sensors: Beacons and Temperature Sensors. The first one is responsible for positioning a mobile device inside a classroom and the second reads the environment temperature. In chapter 5 is described in detail how these sensors work. Also, the system has a built-in display working as an actuator to display the computed output for a student.
- **Control Layer** – The control layer is responsible for deciding the behavior of the system based on events of the physical environment. Using logical decisions, the system will have to compute and check different scenarios such as: If the student is enrolled for the activity; If the student is sitting in the assigned place; etc.
- **Network Layer** – Communication with sensors are performed using two protocols: Bluetooth and 802.11b Wi-Fi. The first one is used between the beacons and mobile device to locate a mobile device inside a classroom. The second one is used to establish communication between the mobile device and the card reader.

Fig. 3.1 presents the architecture installation scheme inside a classroom and Fig. 3.2 details the entrance control system.

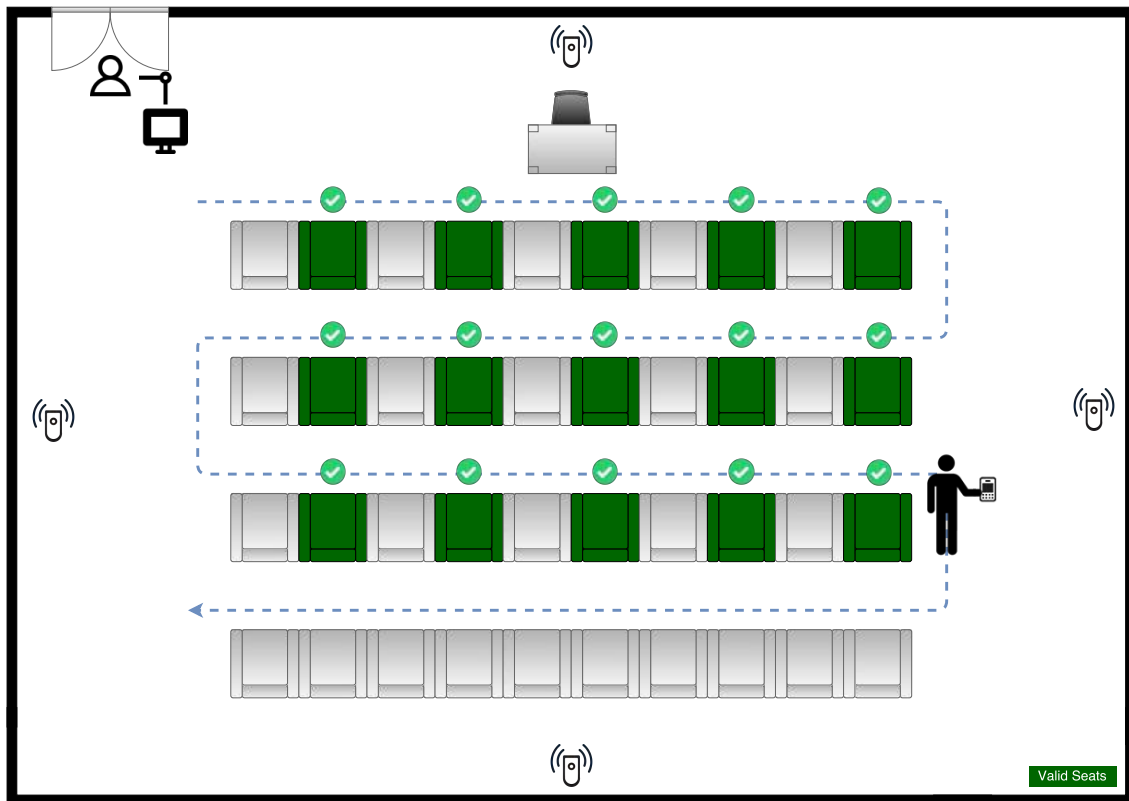


Figure 3.1: Scheme of hardware installation in a classroom environment

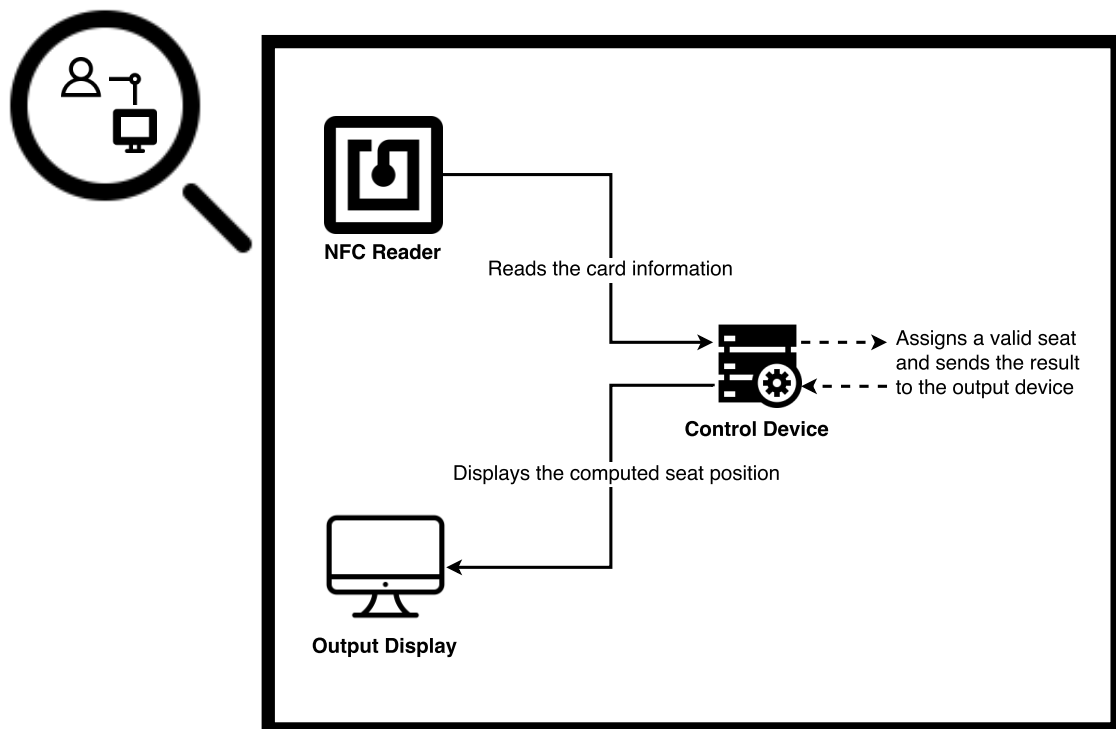


Figure 3.2: Detail of the entrance control system

A SYSTEMATIC LITERATURE REVIEW

This chapter presents a brief research and study about previous works related to the proposed approach of this thesis. It begins by describing the research process in detail, followed by a presentation of the results. Finally, a brief discussion about the selected results is made followed by a summary of relevant information to retain from this chapter.

A [Systematic Literature Review \(SLR\)](#) is a rigorous process to extensively review all available literature relevant to a particular subject. In order to investigate the work previously developed in the context of this thesis, an approach proposed by Barbara Kitchenham was followed [[Kee07](#)].

This process allows through well-defined methodologies to investigate, classify and summarize relevant studies that fulfill various selection criteria.

4.1 Research Method

During the planning of this research and following the guidelines in [[Kit+09](#)], four main tasks were identified before starting:

1. Identify and establish the [Research Questions \(RQs\)](#);
2. Define the search process approach to conduct the research;
3. Formalize the inclusion and exclusion criteria to be applied to the results;
4. Define and perform the quality assessment on the results obtained.

4.1.1 Research Questions

The research questions addressed by this study are described below:

- **RQ1** – What studies show or suggest the usage of **CPSs** in the context of education?
- **RQ2** – Which languages or model-based tools were studied recently to model **CPSs**?
- **RQ3** – Which techniques were studied recently to implement an **IPS**?

For each **RQ** addressed was applied the PICOC methodology proposed by Petticrew and Roberts [PR08].

4.1.1.1 RQ1 – What studies show or suggest the usage of CPSs in the context of education?

Goal Description: To identify what has been done using **CPS** in education and what kind of services the system provides.

Search String: "Cyber-Physical System*" [AND] "Education"

PICOC

- **Population:** Studies regarding **CPSs**;
- **Intervention:** Services or activities provided by **CPSs**;
- **Comparison:** N/A;
- **Outcome:** Evidence of **CPS** applications;
- **Context:** **CPSs** in education environments.

4.1.1.2 RQ2 – Which languages or model-based tools were studied recently to model CPSs?

Goal Description: To identify and compare evidence in terms of modeling languages, conventions, formalities and tools to support the modeling of **CPSs** in a top-down approach.

Search String: "Model*" [AND] "Cyber-Physical System*" [AND] "Model-Based" [AND] "Language*"

PICOC

- **Population:** CPSs;
- **Intervention:** Approaches and frameworks used to model CPSs;
- **Comparison:** Different approaches and frameworks used to model CPSs;
- **Outcome:** Examples of CPSs modeled with different approaches;
- **Context:** Model-based approaches.

4.1.1.3 RQ3 – Which techniques were studied recently to implement an IPS?

Goal Description: To identify and compare evidence in terms of techniques and technologies used in IPSs to locate targets inside buildings.

Search String: "Technique*" [AND] "Indoor Positioning" [AND] "location" [AND] "Fingerprint*"

PICOC

- **Population:** IPSs;
- **Intervention:** Techniques and technologies used recently;
- **Comparison:** N/A;
- **Outcome:** Decide the most appropriate technology to use in the case study;
- **Context:** N/A.

4.1.2 Search Process

In order to perform the SLR, several well-known digital libraries were selected within the scientific community to provide content.

Table 4.1: Sources of evidence

Source	Acronym
ACM Digital Library	ACM
IEEE Xplore Digital Library	IEEEEX
ResearchGate	RG
ScienceDirect	SD
Springer Link	SL

4.1.3 Selection Criteria

In order to refine and filter the set of results obtained in each [RQ](#), a selection criteria to include and exclude studies was defined. Through this selection, the potential selected studies will have a higher probability to answer the corresponding [RQs](#). As a result, the inclusion criteria outlined is the following:

- Studies where at least one of the keywords that form the search string appears in the publication title;
- Studies where at least one of the keywords that form the search string appears in the publication abstract;
- Studies which abstract is related to the same context of this work;
- Source of knowledge is written in English.

On the contrary, the exclusion criteria is the opposite of inclusion criteria.

4.1.4 Quality Assessment

The aim of this section is to assess the quality of the research performed and the selected studies during this process. Following the [Quality Assessment \(QA\)](#) questions outlined by Kitchenham et al. [[Kit+09](#)], the following [QAs](#) were obtained:

- **QA1** – Are the review’s inclusion and exclusion criteria described and appropriate?
- **QA2** – Is the literature search likely to have covered all relevant studies?
- **QA3** – Did the reviewers assess the quality/validity of the included studies?
- **QA4** – Were the basic data/studies adequately described?

With regard to **QA1**, the inclusion criteria was detailed in section [4.1.3](#) and is appropriate to the study conducted. Also, the exclusion criteria was mentioned, considering the opposite of inclusion criteria. Therefore, any study that not met all the inclusion criteria conditions was discarded.

Moreover, for **QA2**, the research was conducted in five digital repositories well-known within the scientific community, as mentioned in section [4.1.2](#). Considering these factors, it can be concluded that the research obtained all relevant studies.

Also, for **QA3**, the quality/validity of data was also considered, ensuring that authors were experts from the addressed study area and that the data presented were corroborated by other authors.

Finally, for **QA4**, in sections [4.2.1](#), [4.2.2](#) and [4.2.3](#) was performed a brief summary of each selected study. Ahead, in chapter [5](#) are presented the results in further detail.

4.1.5 Data Collection

The data extracted from each result were the following:

- Title;
- Author(s);
- Keywords;
- Year;
- Location (URL);
- Source of Evidence;
- Date of Publication;
- Personal Impressions.

4.1.6 Data Analysis

The extracted data from studies was tabulated to present:

- **No. Studies Found** – Represents the number of studies¹ found in each digital repository for each [RQ](#);
- **No. Potential Studies** – Represents the number of filtered studies after applying the inclusion and exclusion criteria for each [RQ](#);
- **No. Selected Studies** – Represents the number of selected studies relevant to this thesis after reading the full text article.

¹Primary studies.

4.2 Results

The aim of this section is to analyze the results of the [SLR](#). In each statistics table, each column representation is defined in section 4.1.6. Also, duplicated results were ignored when considering the number of studies found.

4.2.1 Results for RQ1

Table 4.2: Statistics of search results for RQ1

Digital Library	No. Studies Found	No. Potential Studies	No. Selected Studies
ACM	15	0	0
IEEE Xplore	16	3	1
ResearchGate	10	0	0
ScienceDirect	3	0	0
Springer Link	14	0	0
Total	58	3	1

Table 4.3: Summary of selected results for RQ1

Reference	Summary
[Lei+13]	This paper proposes a CPS to analyze and control the thermal environment of an academic laboratory in order to optimize the performance of the experiments conducted.

4.2.2 Results for RQ2

Table 4.4: Statistics of search results for RQ2

Digital Library	No. Studies Found	No. Potential Studies	No. Selected Studies
ACM	30	4	1
IEEE Xplore	56	13	5
ResearchGate	14	2	1
ScienceDirect	11	2	0
Springer Link	17	0	0
Total	128	21	7

Table 4.5: Summary of selected results for RQ2

Reference	Summary
[Der+12b]	This paper discusses the various challenges of CPS modeling, proposes solutions to address this problems, identifies various tools and technologies used to model CPSs and exemplifies the modeling of a fuel tank of an airplane.
[Fri11]	This paper addresses the Modelica and ModelicaML modeling languages and introduces the OpenModelica environment. Also, it presents a description of Modelica tool and several advantages over the Simulink tool. Finally, enumerates a set of modeling tools depending on each type of CPS modeling.
[Tan+12]	This paper describes the Modelica tool and discusses why Modelica is capable to model and simulate CPSs.
[Jen+11]	This paper proposes a design methodology of CPSs and for each different design stage, a description of the process is made. To conclude, it is proposed a CPS using the approach proposed by the authors, describing each step in the context of the problem.
[Lat+12]	This paper presents a framework called CyPhyML and explores its characteristics to model CPS.
[Nak+12]	This paper shows a comparison between modeling tools SysML and Simulink in relation to the modeling and design of CPS.
[Waw+15]	This paper introduces a tool proposed by the authors named SICYPHOS. This tool based on SysML is compared with existing state of the art solutions.

4.2.3 Results for RQ3

Table 4.6: Statistics of search results for RQ3

Digital Library	No. Studies Found	No. Potential Studies	No. Selected Studies
ACM	0	0	0
IEEE Xplore	63	9	6
ResearchGate	0	0	0
ScienceDirect	4	0	0
Springer Link	44	4	0
Total	111	13	6

Table 4.7: Summary of selected results for RQ3

Reference	Summary
[AA+14]	This paper compares state-of-the-art algorithms, techniques and technologies used in IPs and present the advantages and disadvantages of each technique and technology. Also, the authors focus performance metrics of IPs .
[Dar+15]	This paper presents a comparison of existing IPs , detailing the measurement technique, accuracy, advantages and disadvantages of each technology.
[Kim+15]	This paper describes current IPS techniques and analyzes various security threats and vulnerabilities of IPS .
[FH15]	This paper proposes an IPS using BLE beacons. Further, the authors presents advantages and drawbacks of this technology and perform an experimentation aiming to check the performance of the system with different configuration parameters.
[Ji+15]	This paper presents a comparison of an indoor location system using two different technologies: Wi-Fi access point signals or BLE signals. Besides the theoretical analysis, it presents an experience which compares the degradation of strength due to the distance from the signal transmitter and the accuracy error of the different technologies.
[Liu+07]	This paper introduces existing IPs and techniques used to calculate the target position. Also it presents a set of properties that characterize these systems. However, since this paper was published in 2007, it will only be used as a reference owing to the fact that technology is out-of-date.

4.3 Discussion

Based on the small result set number of papers related with [RQ1](#), it can be argued that the low number of results would be expected to collect. According to the ideas presented in section [3.1](#), it is proposed to develop a groundbreaking case study using a [CPS](#) approach and nowadays, [CPSs](#) are seldom used in the context of education. During the snowball process, there were some potential papers that address the lack of engineers in the area of [CPS](#) or the need to specialize and certify students in emerging technologies. In some cases, simplified and small systems have been developed to test and apply knowledge acquired in classes.

Moreover, the result set from [RQ2](#) explored several modeling languages and tools with different capabilities. Also, some researchers have proposed prototype tools but for pragmatic reasons related to the purpose of the work, we will only consider commercial tools that follow the standard proposed by the [Object Management Group \(OMG\)](#). Since the proposed system is discrete, the language/framework chosen must have the capability to model and simulate the system, which will be a criteria to be taken into account to make the choice. Most importantly, the language must be able to model the system without being dependent on the hardware or technology chosen.

Additionally, based on the results of [RQ3](#), it can be argued that it is a fairly investigated area with various techniques and technologies proposed in the past. However, knowing the technology evolves quickly, there was a special attention to studies published before 2010 since the presented technology may be out of date.

4.4 Summary

After examining the available literature identified in tables [4.3](#), [4.5](#), and [4.7](#), we are able to state that [CPSs](#) were seldom used in the education context. Moreover, considering the outcome of [RQ1](#), it can be concluded that there is no solution similar to what we intend to develop, justifying that one of the outcomes of this work is a groundbreaking case study.

Furthermore, in [RQ2](#), there was obtained a large set of modeling languages, were some of them were prototypes proposed by several investigators. From this result set, we will only consider commercial tools that follow the proposed standards.

Finally, in [RQ3](#), it was found that this topic is subject to intensive research and there are already many techniques and technologies proposed. The selection criteria will take into account factors such as cost and accuracy.

RELATED WORK

This chapter contains a detailed analysis of the results selected in the previous chapter. For each research question, a comparison is made between the various available solutions, ending each section with a detailed analysis of the chosen solution.

5.1 Modeling Cyber-Physical Systems

As previously mentioned, CPS modeling is a sophisticated task due to the scale and heterogeneity of the system [Der+12b; Lee+08]. Many researchers propose tools such as SICYPHOS [Waw+15], Ptolemy [Der+12b] or CyPhyML [Lat+12]. However, we intend to analyze only stable frameworks widely accepted by the research community.

Analyzing the set of results obtained in RQ2 and verifying which are the most commonly used tools/frameworks to model CPSs, resulted in the following selection:

- LabVIEW;
- Modelica;
- ModelicaML;
- Simulink;
- SysML.

5.1.1 Comparison of Frameworks/Tools

According to Fritzson, some tools are specialized in a single application domain while others are more general. For that reason, the author suggests that Simulink and consequently LabVIEW are used by convention to model continuous systems. Although it is proposed in the case study a discrete system, it is intended to use a scalable modeling solution, allowing the evolution of a discrete system to a hybrid system [Fri11].

Moreover, SysML is a hybrid graphical modeling language capable of creating high-level system models that may cover different domain aspects and capture complex system descriptions such as structure, behavior, properties and requirements [Par+10]. Based on the **Unified Modeling Language (UML)** notation, SysML can model both continuous and discrete systems using a reuse design approach by decomposing the whole system into various subsystems [Nak+12]. However, SysML only has the potential to describe the system behavior but cannot simulate its execution unlike Modelica or ModelicaML [Pop+07].

On the other hand, Modelica is a hybrid object-oriented mathematical modeling language with powerful simulation capabilities [Lat+12]. This language allows to describe models using a declarative, modular and hierarchical approach that combines different formalities. Among the several advantages over existing modeling tools, Pop et al. stated that Modelica features the ability to naturally correspond the structure of the model to the physical structure of the system unlike block-oriented modeling tools such as Simulink [Fri11; Pop+07].

The descriptive and graphical capabilities of SysML and the expressiveness and simulation power associated with Modelica led to the creation of a single complete language: **ModelicaML**. This tool benefits of the graphics capabilities offered by UML/SysML with the expressiveness and simulation capabilities of Modelica, allowing verification and validation of system requirements [Sch+09].

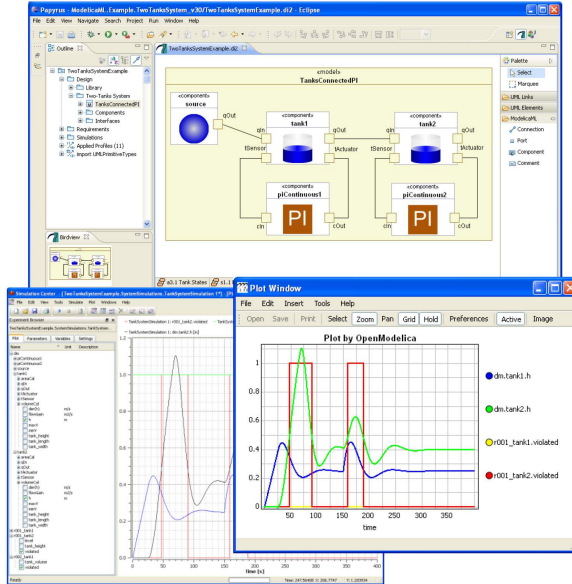
5.1.2 ModelicaML

With regard to what was argued in section 5.1.1, evidence suggests that ModelicaML has all capabilities needed to model the system proposed in the case study.

ModelicaML is a UML profile for Modelica, based on a subset of UML and SysML concepts that allows in an effective way to create and interpret Modelica models. Moreover, since ModelicaML extends a subset of UML, reuses SysML artifacts, and provides new types of diagrams that were missing in Modelica concepts, allows to offer powerful executable diagrams with precise semantics based on Modelica language [Sch+09].

When the modeler wants to execute and simulate the modeled system, ModelicaML models are converted to Modelica code and compiled in Modelica tool. The concept of execution is described in Fig. 5.1.

1 System Modeling with ModelicaML



2 Modelica Code Generation

```

1 within TwoTanks;
2
3 function initValue
4
5   input Real pIn;
6   input Real pOut;
7   output Real pIn;
8   output Real p;
9
10
11   Algorithm
12   // code generated from the Activity "Algorithm (diagram)"
13   // Activity name: "Algorithm (diagram)"
14   if p < pIn then
15     pIn := pIn; // Operation name: "pIn := pIn"
16   elseif p > pOut then
17     p := p;
18   end if;
19
20   within DesignModel;
21
22   TwoTanksSystemExample.DesignModel.LiquidSource source(flowLevel = 0.05);
23   TwoTanksSystemExample.DesignModel.LiquidSink sink(flowLevel = 0.05);
24   TwoTanksSystemExample.DesignModel.LiquidFlow flow(flowLevel = 0.05);
25   parameter Real tankLength = 1; // Tank length
26   parameter Real tankWidth = 1; // Tank width
27   parameter Real tankHeight = 1; // Tank height
28
29   within DesignModel;
30
31   model TankConnectedPI
32
33     TwoTanksSystemExample.DesignModel.LiquidSource source(flowLevel = 0.05);
34     TwoTanksSystemExample.DesignModel.LiquidSink sink(flowLevel = 0.05);
35     TwoTanksSystemExample.DesignModel.LiquidFlow flow(flowLevel = 0.05);
36     TwoTanksSystemExample.DesignModel.PIController piController(ctrl = 0.25);
37     TwoTanksSystemExample.DesignModel.PIController piController2(ctrl = 0.4);
38
39     equation
40       connect(source, flow, tank1.qIn);
41       connect(piController1, tank1.qIn, tank1.qOut);
42       connect(piController2, tank2.qIn, tank2.qOut);
43       connect(tank1.qOut, tank2.qIn);
44       connect(piController1, tank2.qIn, tank2.qOut);
45       connect(piController2, tank2.qIn, tank2.qOut);
46     end equation
47   end TankConnectedPI;
48
49 end TwoTanks;

```

3 System Simulation with Modelica Tools

Figure 5.1: ModelicaML execution concept [Sch13]

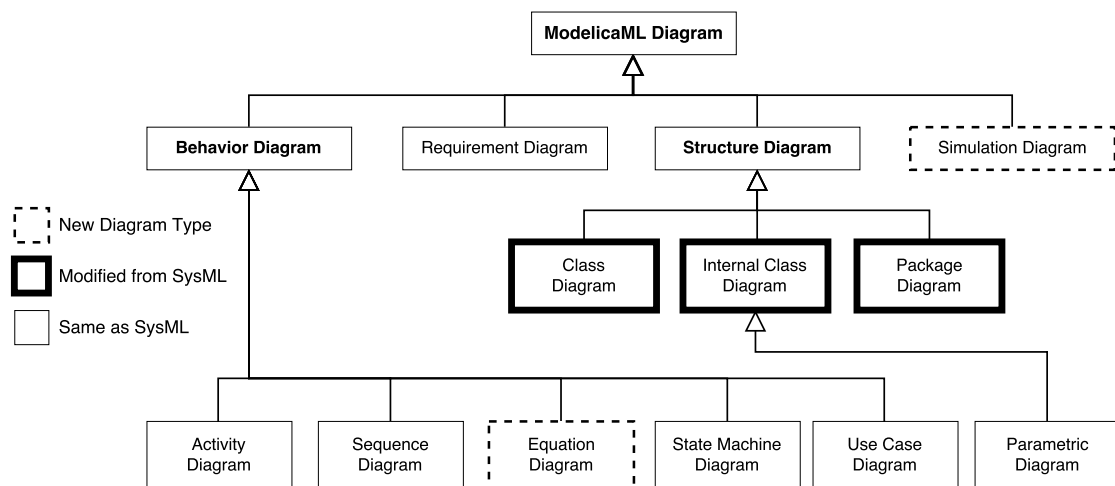


Figure 5.2: ModelicaML diagram overview [Pop+07]

Fig. 5.2 shows the most relevant profile diagrams available in ModelicaML. As shown in the figure, Requirement, Activity, Sequence, State Machine, Use Case and Parametric diagrams are reused from SysML and have the following utility [Omg]:

- **Requirement Diagram** – Allows the composition of system requirements;
- **Activity Diagram** – Allows to demonstrate the behavior of the system using data or control flows. The activities can be composed or decomposed;
- **Sequence Diagram** – Allows to model the interaction between system parts based on a time sequence;
- **State Machine Diagram** – Allows to describe the state actions/transactions that a system/subsystem perform in response to events;
- **Use Case Diagram** – Allows the capture of interaction between external actors with the system or subsystems;
- **Parametric Diagram** – Allows to represent constraints on system property values such as performance or reliability.

Also, Internal Class, Class and Package diagram were reused from SysML diagram taxonomy with slight changes [Pop+07]:

- **Class Diagram** – Renamed from SysML/Block Definition Diagram – Responsible for class definitions and relationships between classes;
- **Internal Class Diagram** – Renamed from SysML/Internal Block Diagram – Describes internal class structure and interconnections between parts;
- **Package Diagram** – Responsible for supporting specifics of Modelica packages.

To conclude, Simulation and Equation diagrams were added to ModelicaML profile:

- **Simulation Diagram** – Allows to configure parameter settings and variables in order to simulate the execution of the system;
- **Equation Diagram** – Specifies the behavior of each component using equations.

An example using the graphical notation of ModelicaML is presented in Fig. 5.3.

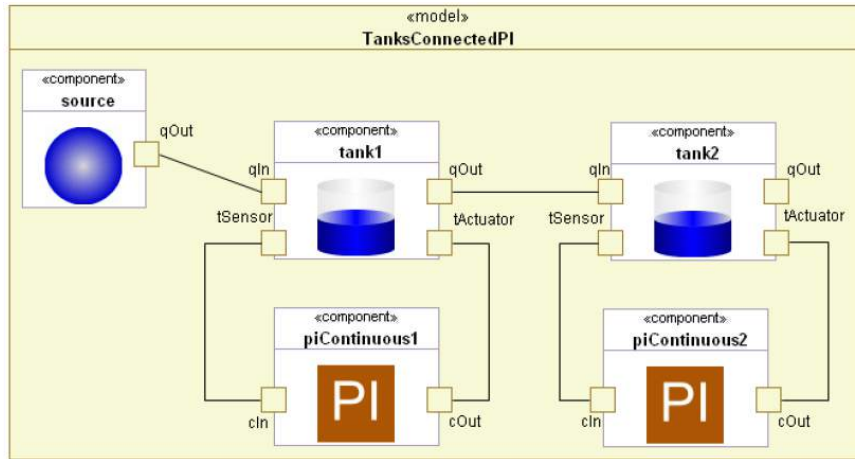


Figure 5.3: ModelicaML graphical notation – Two tanks system example [Sch13]

5.2 Indoor Positioning Systems

As mentioned before, [GPSs](#) lose significant power indoors due to the signal attenuation caused by construction materials [Kjæ+10]. For this reason, an [IPS](#) is needed to locate targets inside buildings.

Analyzing the set of results obtained in RQ3, it was found that it is a fairly investigated area with a large amount of available technological solutions that offer different features.

5.2.1 Comparison of Techniques and Technologies

Al-Ammar et al. identified several metrics to describe an [IPS](#) [AA+14]:

- **Accuracy** – Defines the quality between the measured distance and the actual distance;
- **Availability** – Defines the percentage of time that the system is available to be used ensuring the accuracy described;
- **Cost** – Defines the cost of the hardware, system maintenance and energy consumed to keep the system running;
- **Coverage Area** – Defines the maximum area coverage that the system can cover to locate targets successfully;
- **Privacy** – Defines the data privacy policies collected by sensors and access control permissions over the system;
- **Scalability** – Defines the capability of the system to operate properly regardless the physical context and the number of users present in the environment.

Following the metrics presented above, the proposed system must have a good accuracy, cover at least the entire environment in a classroom, have high scalability and have a low cost of execution and implementation. In order to review the most used existing technological solutions, Tab. 5.1 is presented to compare each technology aspect, with data taken from [AA+14] and [Dar+15].

Table 5.1: Comparison of existing indoor position technologies [AA+14; Dar+15]

Technology	Accuracy	Advantages	Disadvantages
Bluetooth Low Energy (BLE)	Connectivity Range	High compatibility with a wide range of devices; Good indoor coverage with low power consumption; Cheap hardware.	Larger areas increase the cost of installation since it is necessary to buy more receivers to maintain accuracy; Vulnerable to signal interference since it operates in an unlicensed band.
Cellular Based	20m - 500m ¹	No interference with other devices.	Low accuracy due to signal attenuations.
RFID	Connectivity Range	Good indoor coverage with low power consumption; Good propagation of signal through obstacles.	Hard integration with other systems; Unsecured communication.
Ultra-Wideband (UWB)	0.1m - 1m	High accuracy; Good propagation of signal through obstacles; No interference with other devices.	High cost of hardware; Some materials may interfere with the signal.
Wi-Fi	1m - 5m	Cheap hardware; Line of sight between transmitter and receiver is not required; High compatibility with a wide range of devices;	Require Wi-Fi fingerprinting; Physical activities in the environment may change the signal strength.
ZigBee	1m - 10m	Cheap hardware with low power consumption;	Relatively low accuracy; Vulnerable to signal interference since it operates in an unlicensed band.

Given that accuracy is a crucial factor in the proposed system and regarding the accuracy metric in Tab. 5.1, the Cellular and ZigBee technologies will be discarded from the technological choice available. Also, since UWB technology is expensive and RFID has a hard integration with other systems, both technologies will also be discarded.

In order to choose the technological solution between Bluetooth and Wi-Fi to implement the IPS, both technologies will have to be analyzed in further detail.

According to Kim et al., Bluetooth 4.0 specifications were adopted into Bluetooth standards in 2010 and BLE was released later [Kim+15]. BLE is a wireless standard aimed to Internet of Things (IoT) solutions that provide a similar communication range

¹Differs depending on the network available: 2G, 3G or LTE.

as Bluetooth classic but with reduced power consumption, since it is not connection oriented [Ble].

Ji et al. conducted a detailed analysis using Wi-Fi based stations and BLE beacons [Ji+15]. A beacon is a small device that uses BLE technology and broadcasts an advertising package described in Fig. 5.4.

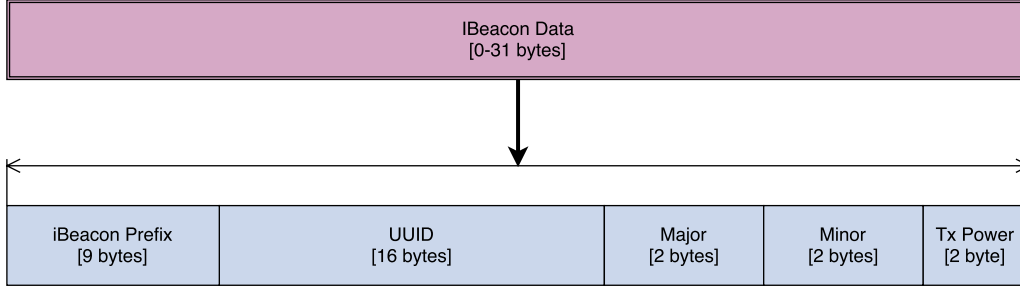


Figure 5.4: iBeacon data format [App14]

When the mobile device receives the advertising package, the distance between the mobile device and the beacon station can be measured using the beacon ID and the signal strength. Although the distance can be computed using a single beacon device, accuracy can be improved by adding more beacons into the physical plant [Kim+15].

BLE operates using a 2.4GHz unlicensed band as well as Wi-Fi but with lower Transmission Power (Tx) and short duration messages to improve battery life. For that reason, more beacons are needed to archive similar accuracy when compared to Wi-Fi technology. Also, battery life depends on configuration parameters such as transmission power or advertise rate [FH15].

In order to compare both technologies, Ji et al. setup a test environment and used two different mobile devices to receive the advertise packages and compare the signal strength of both technologies over different distances.

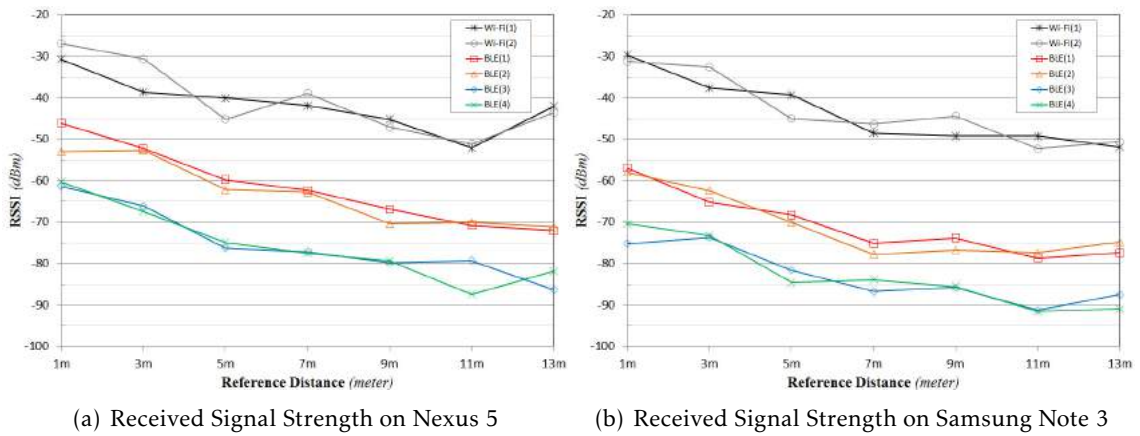


Figure 5.5: Experimental results of received signal strength for Wi-Fi and BLE [Ji+15]

Based in Fig. 5.5, evidence suggests that distinct mobile devices may obtain different measurements. Also, the authors simulated different strategies of transmitters distribution: Random Topology and Grid Topology. The full analysis is published in [Ji+15].

Furthermore, Faragher and Harle identified several challenges related to the use of Wi-Fi technology [FH15]:

- **Long duration of Wi-Fi scans** – Wi-Fi tethering is relatively slower when compared to BLE scan. Hence, the update of the target position is slower using Wi-Fi;
- **Increased network traffic** – Broadcast packets used for communication between transmitters and mobile devices increase network traffic and reduce data transmission rates;
- **Limited access to Wi-Fi services** – Some platforms do not allow access to Wi-Fi services directly, preventing third-party applications to perform Wi-Fi tethering or fingerprinting;
- **Higher energy consumption at the mobile device** – Wi-Fi tethering requires more energy at the mobile device than BLE scan since BLE protocol was developed and optimized considering continuous scan operation.

Also, the authors concluded that BLE technology is more accurate, since the results showed “accuracies of <2.6m 95% of the time using a dense beacon distribution (1 beacon per 30 m²) and <4.8m using a lower density distribution (1 beacon per 100 m²) in an environment where Wi-Fi achieved only <8.5m 95% of the time”.

5.2.2 BLE Beacons

With regard to what was argued in section 5.2.1, evidence suggests that BLE technology has all capabilities to implement the IPS required in the case study proposed.

Given the available commercial solutions, it will be used beacons produced by a has named "Estimote". Their product runs on a coin-typed lithium battery and has an autonomy up to 5 years using low energy settings. Also, Estimote Beacons are build using an ARM M0 Cortex processor, BLE antenna, motion and temperature sensors, providing a range of operation up to 70 meters [Esta]. Moreover, Estimote provides an Indoor SDK that allows the developer to map the physical plant using a custom app and see real-time user positions within that space, with an accuracy of 1 to 4 meters depending on location size [Bor15]. However, Indoor SDK requires at least 4 beacons to operate and it is only available for IOS platform, forcing the initial development of the client app to this platform. Also, Indoor SDK works with *Objective-C* [Obj] or *Swift* [Swi], leaving the technology choice to the user's criteria. Fig. 5.6 shows the hardware assembly of a single beacon.

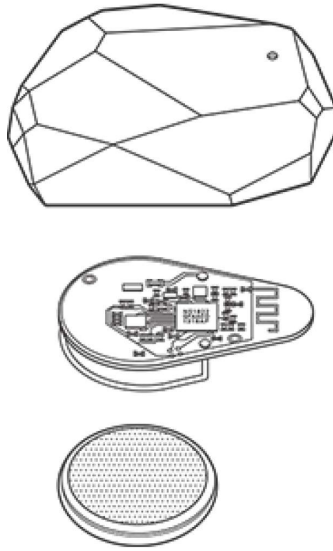


Figure 5.6: Hardware assembly of Estimote beacons [Esta]

5.3 Development Process

In order to develop the proposed system, Jensen et al. have identified a number of steps aimed to support the modeling and development of **CPSs**. The proposed methodology addresses the development process from its specification to its realization and is divided into several codependent steps [Jen+11]:

1. **State the Problem** – The first step is to define the problem to be solved with clear textual language so that anyone can understand what is intended to do;
2. **Model Physical Process** – The second step is to start sketching the physical model by analyzing the environment and the physical processes that are going to interact with the **CPS**;
3. **Characterize the Problem** – The third step is to identify parameters of physical processes to be controlled. For instance, parameters such as room capacity or fault conditions;
4. **Derive a Control Algorithm** – The fourth step is to establish a control algorithm to be implemented and executed in the control layer of the **CPS**;
5. **Selects Models of Computation** – The fifth step is to define *models of computation* that contain the set of allowable operations used in computation and the rules of interaction between entities;
6. **Specify Hardware** – The sixth step is to specify the required hardware to build the **CPS**. The hardware selected must be capable of fulfill the behavior and the features modeled in *Step 2*;

7. **Simulate** – The seventh step is to simulate the CPS in a virtual environment before assembling the hardware. This step avoid mistakes that can be costly at a further stage.
8. **Construct** – The eighth step is to build the system according to specifications. Each subsystem must be build and tested until the full CPS is completed.
9. **Validation and Testing** – The ninth step is to test the CPS and validate if the specified requirements are fulfilled. All control conditions must be tested and the system behavior must be equal to the result obtained in *Step 7*.

After reviewing the methodology proposed by the author, we find it suitable to model the proposed system. Therefore, the method presented above will be followed during the development of the CPS proposed in the case study.

CONCEPTUALIZATION AND IMPLEMENTATION

This chapter presents a detailed description of the prototype developed in this dissertation. It begins by introducing the modeling of the system through the requirements engineering processes, followed by the implementation details of the remaining subsystems that complement the proposed solution.

6.1 Requirements Engineering

In order to model and implement the proposed solution, a traditional process of engineering will be followed. Requirements Engineering is a process that aims to find, document, analyze and verify the purposes of a system with the purpose of ensuring that the customer needs are satisfied and the product functionalities are respected, without compromising the requirements of the system to be developed [Som09].

To ensure the solution developed meets a set of functionalities and constraints implicit in the educational system in the most teaching establishments, a feasibility study and the elicitation and analysis of requirements were carried out with the help of domain experts.

After this process was completed, the system modeling process was started.

6.1.1 Use Case Diagram

By analyzing the requirements collected with the domain experts that contains the features and constraints of the system, a use-case diagram was modeled as a ModelicaML use case diagram. Fig. 6.1 shows the use case diagram.



Figure 6.1: E-Presence System - ModelicaML use case diagram

6.1.2 Use Case Descriptions

The use cases specified in subsection 6.1.1 are further detailed and accomplished with use case descriptions. The template used is based on the use case template presented by Larman [Lar04].

Use Case 1	Login
<i>Description:</i>	This use case describes how the Faculty Member authenticates into the E-Presence app.
<i>Primary Actor:</i>	Faculty Member.
<i>Preconditions:</i>	<ul style="list-style-type: none">• System must be running;• E-Presence DB must be reachable;• Academic Authentication System must be reachable;• User is not authenticated.
<i>Postconditions:</i>	User is successfully authenticated.
<i>Main Success Scenario:</i> <ol style="list-style-type: none">1. The use case begins when the Faculty Member starts the app;2. The Faculty Member inputs the authentication credentials and submits;3. The system queries the E-Presence database to verify if the credentials submitted are correct;4. The system displays the home display;5. The use case ends successfully.	

Alternatives:

2.a The Faculty Member selects the Academic Sign-In authentication button:

1. The system requests the user credentials in the academic authentication system;
2. The academic authentication system replies the request;
3. The use case resumes at Step 3 of the main scenario.

3.a The system cannot find the user or the password is incorrect:

1. The system displays a feedback message;
 2. The use case ends.
-

Use Case 2	Select Course
<i>Description:</i>	This use case describes how the Faculty Member selects a course using the E-Presence app.
<i>Primary Actor:</i>	Faculty Member.
<i>Preconditions:</i>	<ul style="list-style-type: none">• System must be running;• E-Presence DB must be reachable;• User is authenticated.
<i>Postconditions:</i>	Course is selected successfully.
<i>Main Success Scenario:</i>	
<ol style="list-style-type: none">1. The use case begins when the Faculty Member selects the current course;2. The courses controller queries the E-Presence database to check all courses for which the user authenticated is responsible;3. The system prompts the list of courses fetched;4. The Faculty Member selects the desired course;5. The use case ends successfully.	

Use Case 3	View Students List
<i>Description:</i>	This use case describes how the Faculty Member uses the E-Presence app to view the list of students enrolled in a course.
<i>Primary Actor:</i>	Faculty Member.
<i>Preconditions:</i>	<ul style="list-style-type: none"> • System must be running; • E-Presence DB must be reachable; • User is authenticated.
<i>Postconditions:</i>	The list of students is displayed successfully.
<i>Main Success Scenario:</i>	
<ol style="list-style-type: none"> 1. The use case begins when the Faculty Member selects Students; 2. The students controller queries the E-Presence database to check all students enrolled in the selected course; 3. The system displays the list of students; 4. The use case ends successfully. 	

Use Case 4	View Student Details
<i>Description:</i>	This use case describes how the Faculty Member uses the E-Presence app to view the details of a student.
<i>Primary Actor:</i>	Faculty Member.
<i>Preconditions:</i>	<ul style="list-style-type: none">• System must be running;• E-Presence DB must be reachable;• User is authenticated;• The student record is created.
<i>Postconditions:</i>	Student details are displayed successfully.
<i>Main Success Scenario:</i> <ol style="list-style-type: none">1. The use case begins when the Faculty Member selects the student;2. The students controller queries the E-Presence database to find the selected student;3. The system displays the details of the student;4. The use case ends successfully.	

Use Case 5	View Activity Schedule
<i>Description:</i>	This use case describes how the Faculty Member uses the E-Presence app to view the evaluation activity schedule.
<i>Primary Actor:</i>	Faculty Member.
<i>Preconditions:</i>	<ul style="list-style-type: none"> • System must be running; • E-Presence DB must be reachable; • User is authenticated.
<i>Postconditions:</i>	Scheduled activities are displayed successfully.
<i>Main Success Scenario:</i>	
<ol style="list-style-type: none"> 1. The use case begins when the Faculty Member selects the Classes or Evaluations mode; 2. If the user is in class mode; <ol style="list-style-type: none"> 1. The turns controller queries the E-Presence database to find all class turns from the selected course and displays the results; 2. The Faculty Member selects a specific turn; 3. The classes controller queries the E-Presence database to find all class activities scheduled for the selected turn and course; 3. Else <ol style="list-style-type: none"> 1. The evaluations controller queries the E-Presence database to find all evaluation activities of the selected course; <p>end if;</p> <ol style="list-style-type: none"> 4. The system displays the results; 5. The use case ends successfully. 	

Use Case 6	Create New Activity
<i>Description:</i>	This use case describes how the Faculty Member uses the E-Presence app to create a new activity.
<i>Primary Actor:</i>	Faculty Member.
<i>Preconditions:</i>	<ul style="list-style-type: none">• System must be running;• E-Presence DB must be reachable;• User is authenticated.
<i>Postconditions:</i>	New activity is created successfully.
<i>Main Success Scenario:</i>	
<ol style="list-style-type: none">1. The use case begins when the Faculty Member selects Create New Activity;2. If the user is in class mode;<ol style="list-style-type: none">1. The classes controller queries the E-Presence database to check all available rooms;3. Else<ol style="list-style-type: none">1. The evaluations controller queries the E-Presence database to check all available rooms; <p>end if;</p> <ol style="list-style-type: none">4. The system displays the form that prompts the activity description name, room, start time, end time and the time allowed to enter before the activity starts and the time allowed to leave before the activity ends;5. The Faculty Member submits the requested information;6. The system displays a feedback message;7. The use case ends successfully.	

Use Case 7	Edit Activity Details
<i>Description:</i>	This use case describes how the Faculty Member uses the E-Presence app to edit an activity.
<i>Primary Actor:</i>	Faculty Member.
<i>Preconditions:</i>	<ul style="list-style-type: none">• System must be running;• E-Presence DB must be reachable;• User is authenticated;• The activity to be edited is created.
<i>Postconditions:</i>	Activity details are edited successfully.
<i>Main Success Scenario:</i>	
<ol style="list-style-type: none">1. The use case begins when the Faculty Member selects Edit Activity;2. If the user is in class mode;<ol style="list-style-type: none">1. The classes controller queries the E-Presence database to check all available rooms;3. Else<ol style="list-style-type: none">1. The evaluations controller queries the E-Presence database to check all available rooms; <p>end if;</p> <ol style="list-style-type: none">4. The system displays the edit form filled with the current information;5. The Faculty Member submits the requested information edited;6. The system displays a feedback message;7. The use case ends successfully.	

Use Case 8	Delete Activity
<i>Description:</i>	This use case describes how the Faculty Member uses the E-Presence app to delete an activity.
<i>Primary Actor:</i>	Faculty Member.
<i>Preconditions:</i>	<ul style="list-style-type: none">• System must be running;• E-Presence DB must be reachable;• User is authenticated;• The activity to be edited is created.
<i>Postconditions:</i>	The activity is deleted successfully.
<i>Main Success Scenario:</i> <ol style="list-style-type: none">1. The use case begins when the Faculty Member selects Delete Activity inside the activity detail;2. The system prompts a confirmation message;3. The Faculty Member selects the OK button;4. The system deletes the evaluation activity and displays a feedback message;5. The use case ends successfully.	
<i>Alternatives:</i> <ol style="list-style-type: none">2.a The Faculty Member selects the CANCEL button:<ol style="list-style-type: none">1. Operation is cancelled;2. The use case ends.	

Use Case 9	View Activity Details
<i>Description:</i>	This use case describes how the Faculty Member uses the E-Presence app to view the details about an activity.
<i>Primary Actor:</i>	Faculty Member.
<i>Preconditions:</i>	<ul style="list-style-type: none">• System must be running;• E-Presence DB must be reachable;• User is authenticated;• The activity is created.
<i>Postconditions:</i>	Activity details are displayed successfully.
<i>Main Success Scenario:</i>	
<ol style="list-style-type: none">1. The use case begins when the Faculty Member selects a class activity or an evaluation activity;2. If the user is in class mode;<ol style="list-style-type: none">1. The classes controller queries the E-Presence database to find the selected class activity;3. Else<ol style="list-style-type: none">1. The evaluations controller queries the E-Presence database to find the selected evaluation activity; <p>end if;</p> <ol style="list-style-type: none">4. The system displays the activity details;5. The use case ends successfully.	

Use Case 10	Connect Card Reader
<i>Description:</i>	This use case describes how the Faculty Member uses the E-Presence app to connect a card reader.
<i>Primary Actor:</i>	Faculty Member.
<i>Secondary Actor:</i>	Card Reader System.
<i>Preconditions:</i>	<ul style="list-style-type: none">• System must be running;• Card reader must be running and disconnected;• E-Presence DB must be reachable;• User is authenticated;• Mobile device running the E-Presence app must be in the same network as the card reader.
<i>Postconditions:</i>	Card reader is successfully connected.
<i>Main Success Scenario:</i> <ol style="list-style-type: none">1. The use case begins when the Faculty Member selects Connect Card Reader;2. The system prompts the card reader ID number to connect;3. The user submits the required information;4. The card reader controller queries the E-Presence database to find the authentication credentials for the specified card reader;5. The system tries to connect to the Card Reader System;6. The system displays a feedback message and the card reader lights a blue LED;7. The use case ends successfully.	

Alternatives:

4.a Card reader ID is invalid or not found:

1. The system shows a failure message;
2. The use case ends.

5.a Cannot acquire an IP address:

1. The system shows a failure message;
 2. The use case ends.
-

Use Case 11	Disconnect Card Reader
<i>Description:</i>	This use case describes how the Faculty Member uses the E-Presence app to disconnect a paired card reader.
<i>Primary Actor:</i>	Faculty Member.
<i>Secondary Actor:</i>	Card Reader System.
<i>Preconditions:</i>	<ul style="list-style-type: none">• System must be running;• Card reader must be running and connected;• User is authenticated;• Mobile device running the E-Presence app must be in the same network as the card reader.
<i>Postconditions:</i>	Card reader is successfully disconnected.
<i>Main Success Scenario:</i>	
<ol style="list-style-type: none">1. The use case begins when the Faculty Member selects Disconnect Card Reader;2. The system closes the communication socket with the Card Reader System;3. The system displays a feedback message and the card reader lights a red LED;4. The use case ends successfully.	

Use Case 12	Connect Indoor Positioning System
<i>Description:</i>	This use case describes how the Faculty Member connects the IPS system to the E-Presence app.
<i>Primary Actor:</i>	Faculty Member.
<i>Secondary Actor:</i>	Indoor Positioning System.
<i>Preconditions:</i>	<ul style="list-style-type: none">• System must be running;• IPS must be running and disconnected;• User is authenticated;• Mobile device running the E-Presence app must be in the same network as the IPS.
<i>Postconditions:</i>	IPS is successfully connected.
<i>Main Success Scenario:</i>	
<ol style="list-style-type: none">1. The use case begins when the Faculty Member starts the IPS app;2. The system prompts the IP address of the device running the E-Presence app;3. The user submits the required information;4. The IPS tries to connect to the E-Presence app;5. The IPS displays a feedback message and starts updating the position coordinates values;6. The use case ends successfully.	
<i>Alternatives:</i>	
<ol style="list-style-type: none">4.a Connection cannot be established:<ol style="list-style-type: none">1. The IPS shows a failure message;2. The use case ends.	

Use Case 13	Disconnect Indoor Positioning System
<i>Description:</i>	This use case describes how the Faculty Member uses the E-Presence app to disconnect the IPS .
<i>Primary Actor:</i>	Faculty Member.
<i>Secondary Actor:</i>	Indoor Positioning System.
<i>Preconditions:</i>	<ul style="list-style-type: none">• System must be running;• IPS must be running and connected;• User is authenticated;• Mobile device running the E-Presence app must be in the same network as the IPS.
<i>Postconditions:</i>	IPS is successfully disconnected.
<i>Main Success Scenario:</i>	
<ol style="list-style-type: none">1. The use case begins when the Faculty Member selects STOP or closes the IPS app;2. The IPS closes the communication socket with the E-Presence app;3. The IPS displays a feedback message and stops updating the position coordinates values;4. The use case ends successfully.	

Use Case 14	Assign Student Card
<i>Description:</i>	This use case describes how the Faculty Member uses the E-Presence app to assign a student card to a student record.
<i>Primary Actor:</i>	Faculty Member.
<i>Secondary Actor:</i>	<ul style="list-style-type: none">• Student;• Card Reader System.
<i>Preconditions:</i>	<ul style="list-style-type: none">• System must be running;• E-Presence DB must be reachable;• Card reader must be running and connected;• User is authenticated;• Student record is created;• Student card is not broken.
<i>Postconditions:</i>	Student card is recorded successfully.

Main Success Scenario:

1. The use case begins when the Faculty Member selects Assign Card in a specific student detail;
2. The system displays a feedback message when the card reader and the E-Presence app is ready;
3. The Student taps his/her card in the card reader sensor;
4. The card reader system reads the card ID, flashes a green LED and sends the data to the E-Presence app;
5. The system receives the data and students controller stores the ID in the student record;
6. The system displays a feedback message;
7. The use case ends successfully.

Alternatives:

4.a Card was not read correctly:

1. The card reader flashes a red LED;
 2. The use case resumes at Step 3 of the main scenario.
-

Use Case 15	Entrance Validation
<i>Description:</i>	This use case describes how the Faculty Member uses the E-Presence app to validate the entry of a student in an activity.
<i>Primary Actor:</i>	Student.
<i>Secondary Actor:</i>	<ul style="list-style-type: none"> • Faculty Member; • Card Reader System.
<i>Preconditions:</i>	<ul style="list-style-type: none"> • System must be running; • E-Presence DB must be reachable; • Card reader must be running and connected; • User is authenticated; • Activity is created; • Student is not checked-in.
<i>Postconditions:</i>	Student is checked-in.

Main Success Scenario:

1. The use case begins when the Student taps his/her student card in the card reader when is entering an activity;
 2. **If** the activity is a class;
 1. The activity controller records the attendance details in the E-Presence database;
 3. **Else**
 1. The evaluations controller queries the E-Presence database to check if the student is enrolled;
 2. The system assign a random seat to the Student;
- end if;**
4. The system displays a feedback message;
 5. The use case ends successfully.

Alternatives:

- 1.a Student did not bring his card or card is broken/not recognized:
 1. The Student must ask for assistance from a supervisor;
 2. The Faculty Member selects the Student Number Attendance button;
 3. The Faculty Member submits the required information;
 4. The use case resumes at Step 2 of the main scenario.
 - 2.1.a, 3.1.a Student is not enrolled:
 1. The system shows a failure message;
 2. The Student must ask for assistance from a supervisor;
 3. The use case ends.
 - 2.1.b, 3.1.b Student tries to check-in before allowed time or room is full:
 1. The system shows a failure message;
 2. The use case ends.
-

Use Case 16	In-Place Validation
<i>Description:</i>	This use case describes how the Faculty Member uses the E-Presence app to validate the position of a student during an evaluation activity.
<i>Primary Actor:</i>	Student.
<i>Secondary Actor:</i>	<ul style="list-style-type: none">• Faculty Member;• Indoor Position System;• Card Reader System.
<i>Preconditions:</i>	<ul style="list-style-type: none">• System must be running;• E-Presence DB must be reachable;• Card reader must be running and connected;• IPS must be running, connected and updating the correct coordinates position;• User is authenticated;• Activity is an assessment and is created;• Student is checked-in.
<i>Postconditions:</i>	Student's in-place validation is successful.

Main Success Scenario:

1. The use case begins when the Student taps his/her student card in the card reader when is entering an activity;
 2. The students controller queries the E-Presence database to find the student's data.
 3. The system displays the student's information for visual confirmation;
 4. The Faculty Member validates the information displayed;
 5. The activity controller queries the E-Presence database to obtain the seat position assigned to the student and checks if the student is within a specified radius using the data received from the [IPS](#);
 6. The system displays a feedback message;
 7. The use case ends successfully.
-

Alternatives:

- 1.a Student did not bring his card or card is broken/not recognized:
 1. The Faculty Member selects the Student Number Attendance button;
 2. The Faculty Member submits the required information;
 3. The use case resumes at Step 2 of the main scenario.
 - 3.a Faculty member cancels the operation:
 1. The use case ends.
 - 5.a Student is in the wrong seat or is outside the specified radius:
 1. The system shows a failure message;
 2. The Faculty Member must guide the student to move to the correct seat position;
 3. The use case resumes at Step 1 of the main scenario.
-

Use Case 17	Exit Validation
<i>Description:</i>	This use case describes how the Faculty Member uses the E-Presence app to validate an exit of a student from an activity.
<i>Primary Actor:</i>	Student.
<i>Secondary Actor:</i>	<ul style="list-style-type: none">• Faculty Member;• Card Reader System.
<i>Preconditions:</i>	<ul style="list-style-type: none">• System must be running;• E-Presence DB must be reachable;• Card reader must be running and connected;• User is authenticated;• Activity is created;• Student checked-in in the activity.
<i>Postconditions:</i>	Student's exit validation is successful.

Main Success Scenario:

1. The use case begins when the Student taps his/her student card in the card reader when is entering an activity;
 2. **If** the activity is a class;
 1. The activity controller records the E-Presence database to check if the student checked-in in the activity;
 3. **Else**
 1. The evaluation controller queries the E-Presence database to check if the student's in-place validation was successful;
 2. The system prompts a window to check if the student delivered or not delivered the evaluation's answer sheets.
 3. The Faculty Member selects the appropriate option;
- end if;**
4. The System displays a window to check if the student delivered or not delivered the evaluation sheets;
 5. The Faculty Member selects the appropriate option;
 6. The system displays a feedback message;
 7. The use case ends successfully.

Alternatives:

- 1.a Student did not bring his card or card is broken/not recognized:
 1. The Student must ask for assistance from a supervisor;
 2. The Faculty Member selects the Student Number Attendance button;
 3. The Faculty Member submits the required information;
 4. The use case resumes at Step 3 of the main scenario.
 - 1.b Student tries to check-out before allowed time:
 1. The system shows a failure message;
 2. The use case ends.
-

Use Case 18	Export Activity Report
<i>Description:</i>	This use case describes how the Faculty Member uses the E-Presence app to export the data of an activity.
<i>Primary Actor:</i>	Faculty Member.
<i>Preconditions:</i>	<ul style="list-style-type: none"> • System must be running; • E-Presence DB must be reachable; • User is authenticated; • Activity is created.
<i>Postconditions:</i>	Activity report is exported successfully.
<i>Main Success Scenario:</i>	
<ol style="list-style-type: none"> 1. The use case begins when the Faculty Member selects Export Activity Report; 2. The system exports a report with the details from the activity and send it to the default e-mail client on the mobile device; 3. The use case ends successfully. 	

Use Case 19	Logout
<i>Description:</i>	This use case describes how the Faculty Member uses the E-Presence app to logout a user.
<i>Primary Actor:</i>	Faculty Member.
<i>Preconditions:</i>	<ul style="list-style-type: none">• System must be running;• User is authenticated.
<i>Postconditions:</i>	User is logged out.
<i>Main Success Scenario:</i>	
<ol style="list-style-type: none">1. The use case begins when the Faculty Member selects Logout;2. The system invalidates the current active session;3. The system displays the login form;4. The use case ends successfully.	

6.1.3 Architecture Diagram

A system architecture is a conceptual model that defines the structure, behavior, and views of a system. The architecture can be described using an architecture description that consists in a representation of a system through a formal description to define the structure of the system and the requirements that the system must support [JT10].

Fig. 6.2 illustrates the architecture diagram of the system.

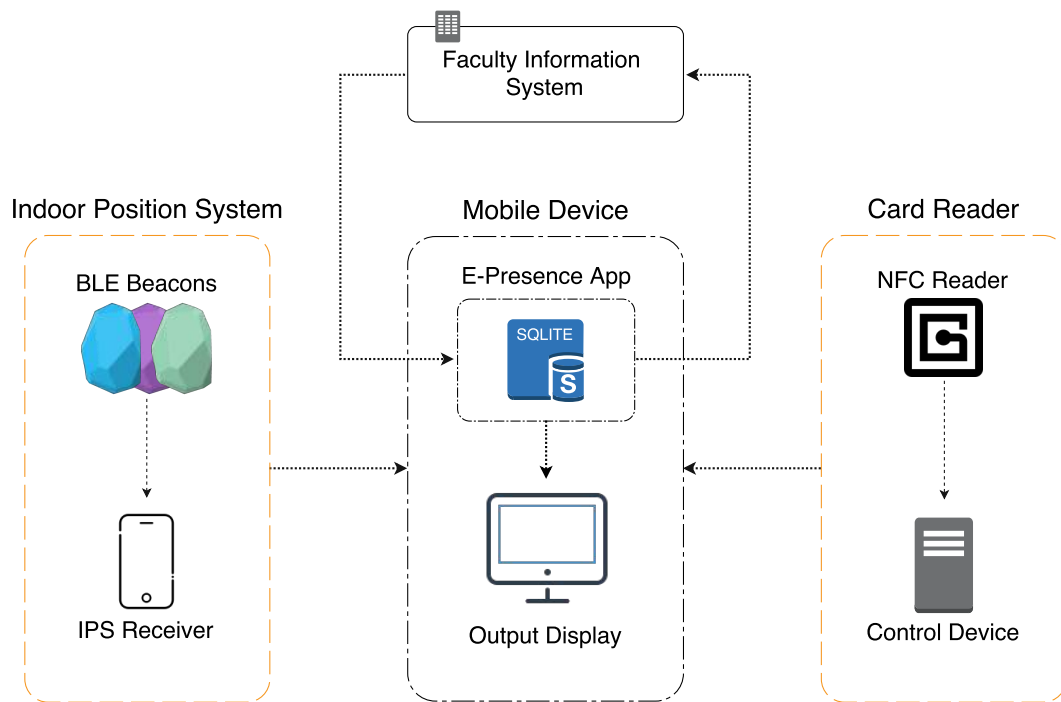


Figure 6.2: E-Presence System - Architecture diagram

6.1.4 Components Diagram

A component diagram completes the architecture modeling by illustrating how components are wired together and which interfaces each component can offer or require in order to build the complete system [Amb04].

Fig. 6.3 shows the component diagram of the system modeled as a ModelicaML component diagram.

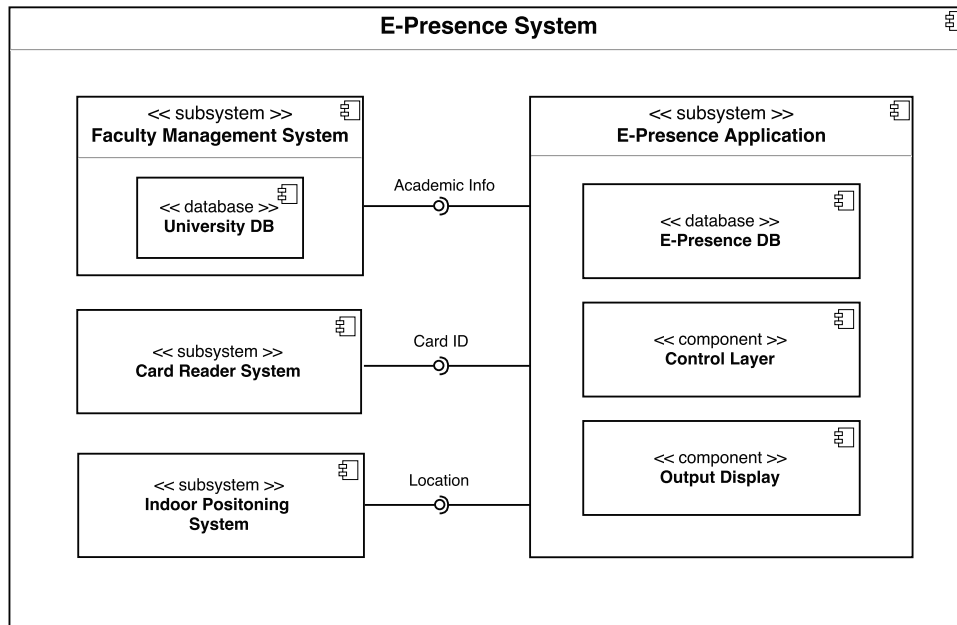


Figure 6.3: E-Presence System - ModelicaML components diagram

6.2 E-Presence App

After analyzing the contents of section 6.1 that defines the functionalities and constraints that the system must meet, the application flow design was started. The app flow is illustrated in Fig. 6.4 followed by an explanation of each functionality implemented.

6.2.1 Functional Specifications

6.2.1.1 Login

When there is no active session or when the user logs out, the authentication fields to login into the application are presented (Fig. 6.5). The user must use his/her academic credentials which, depending on their status, will have access to the various functionalities of the application (Fig. 6.5: Frame 2).

In order to avoid successive user authentication during an evaluation activity, the current session should remain active for a certain period. If the user sign out or the session time expires, authentication will be required again.

6.2.1.2 Courses

In this section, the user can select the course he/she wants to manage from a list of courses which he/she is responsible for (Fig. 6.6). Depending on the option selected (Fig. 6.6: Frame 2), classes, students enrolled and evaluation activities regarding the selected course will be loaded.

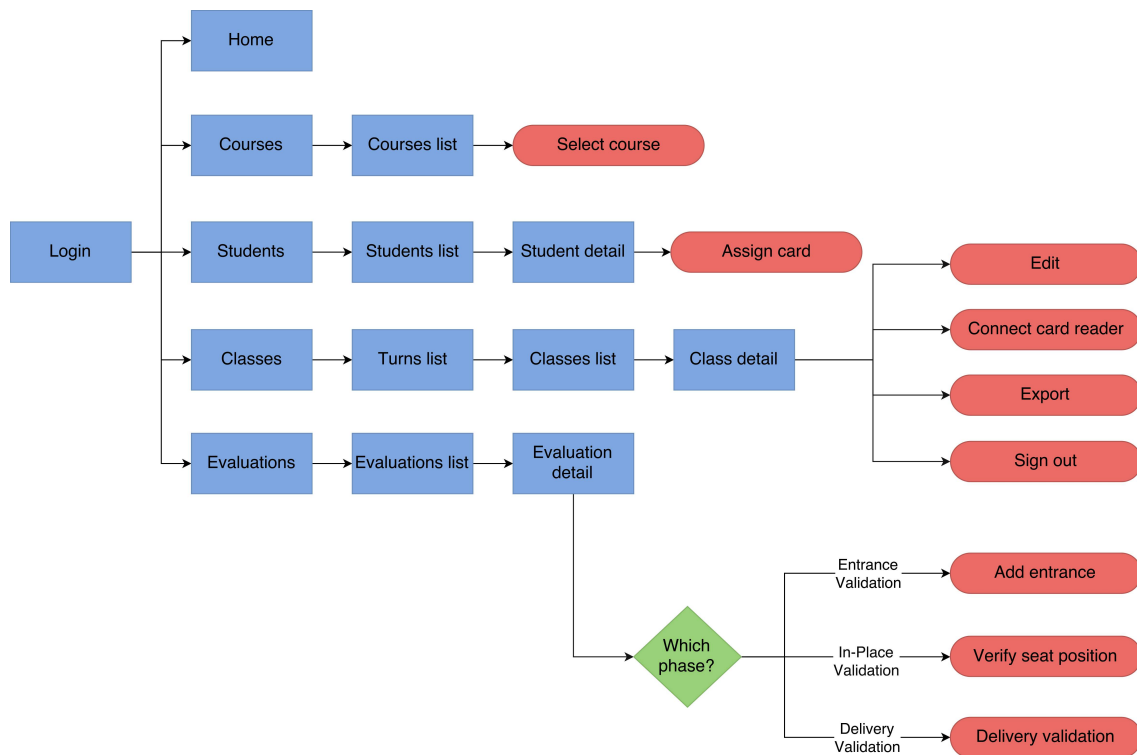


Figure 6.4: E-Presence System - Application flowchart

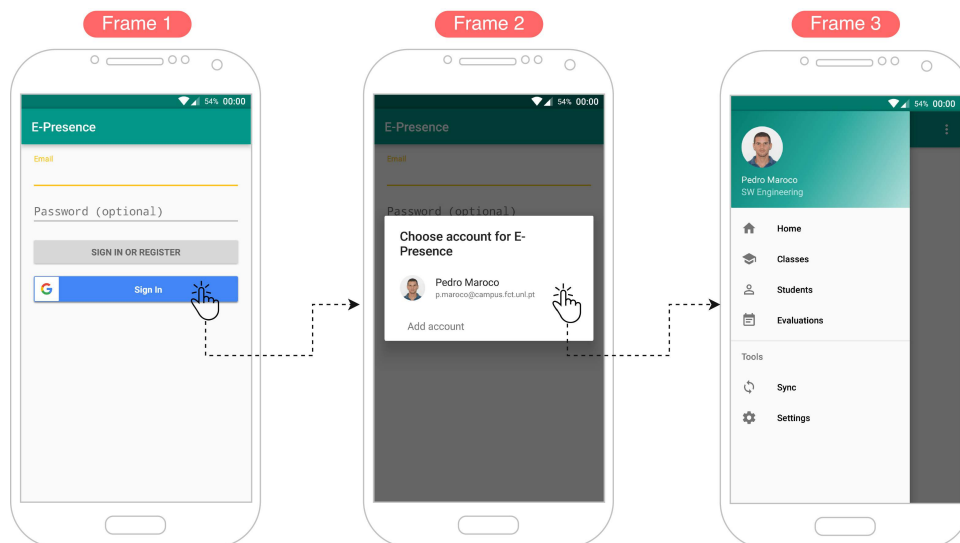


Figure 6.5: E-Presence App - Login app flow

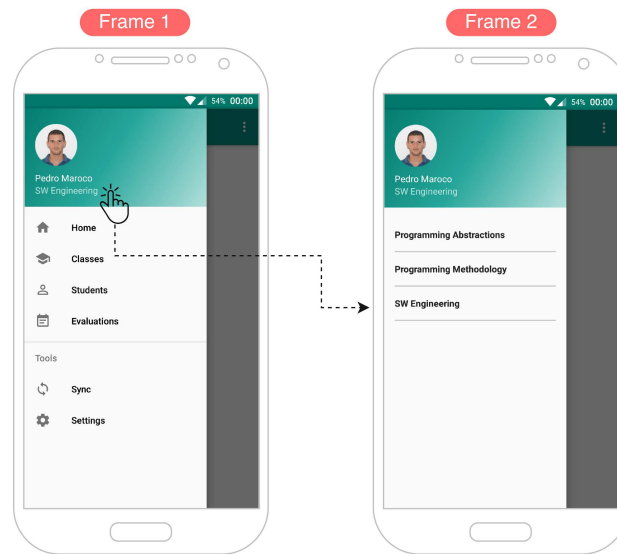


Figure 6.6: E-Presence App - Courses app flow

6.2.1.3 Classes

This section allows the user to check the class schedule and monitor student attendances at classes (Fig. 6.7). Upon entering this section, the list of turns for which the user is responsible is presented (Fig. 6.7: Frame 2). The user can check the list of classes of a certain turn by clicking on it (Fig. 6.7: Frame 3).

After selecting a class, it is possible to check the attendance list or start the attendance control using a connected card reader or by manual mode.

Also, the user can export the list of participants at any time by selecting the Export Attendances option in the class detail menu.

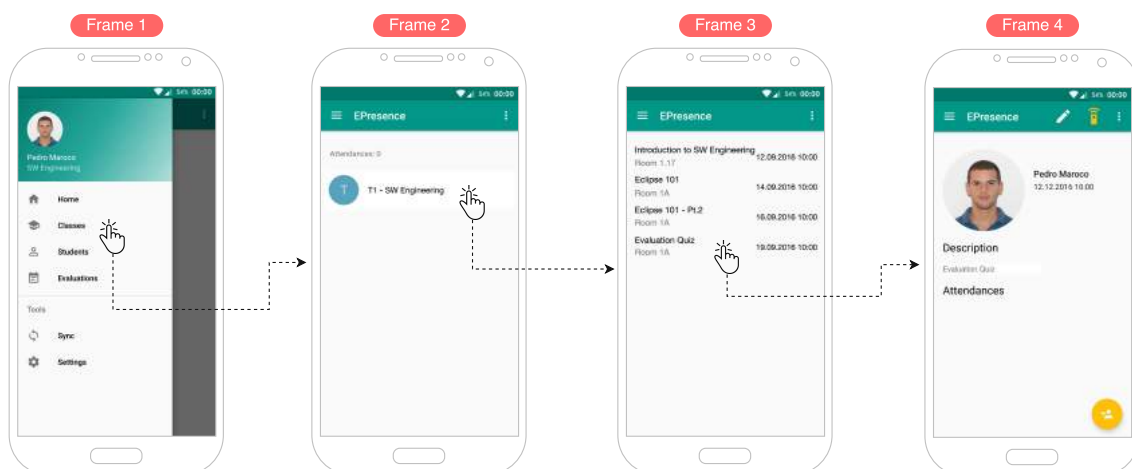


Figure 6.7: E-Presence App - Classes app flow

6.2.1.4 Students

Students section allows the user to check the list of students enrolled in the selected course (Fig. 6.8). In addition to the name and student number, it is possible to check if a student already has his/her student card registered in the application. This information is presented through a colored label next to each element of the list. It is possible to check the details of a particular student such as the summary of their attendances by selecting the desired element from the student list (Fig. 6.8: Frame 2-3).

If a student does not have a registered student card or if the card has been replaced, a new association can be made using the card reader, following the steps described in Fig. 6.8: Frame 3-4.

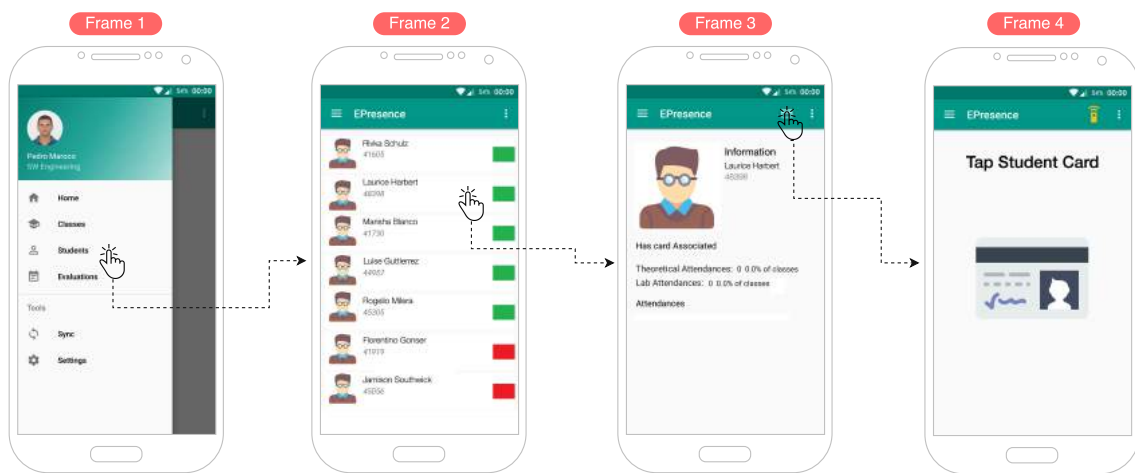


Figure 6.8: E-Presence App - Students flowchart

6.2.1.5 Evaluations

The evaluations section allows the user to check the evaluation activity schedule and monitor student attendances during evaluation activities (Fig. 6.8). In the first screen that appears, the user can check the list of planned evaluation activities for which he/she is responsible or schedule a new evaluation activity (Fig. 6.9(a): Frame 2).

Details such as the device IP address, the list of students participating in a specific evaluation activity or the validation status of each student can be checked if an evaluation activity is selected.

It is possible to connect a card reader at any time by following the steps in Fig. 6.9(a): Frame 4-5-6. If no sensor is connected or if the student card can not be used, the validation must be done manually using the student number (Fig. 6.9(a): Frame 4-7).

Whenever a student card is detected for a new validation, the system will check which was the last validation executed for the same card number to decide which will be the next validation that should be executed (Fig. 6.8(b)). If the student is enrolled for the

evaluation activity and their presence has not yet been registered, the entrance validation is performed successfully (Fig. 6.8(b): Frame 1).

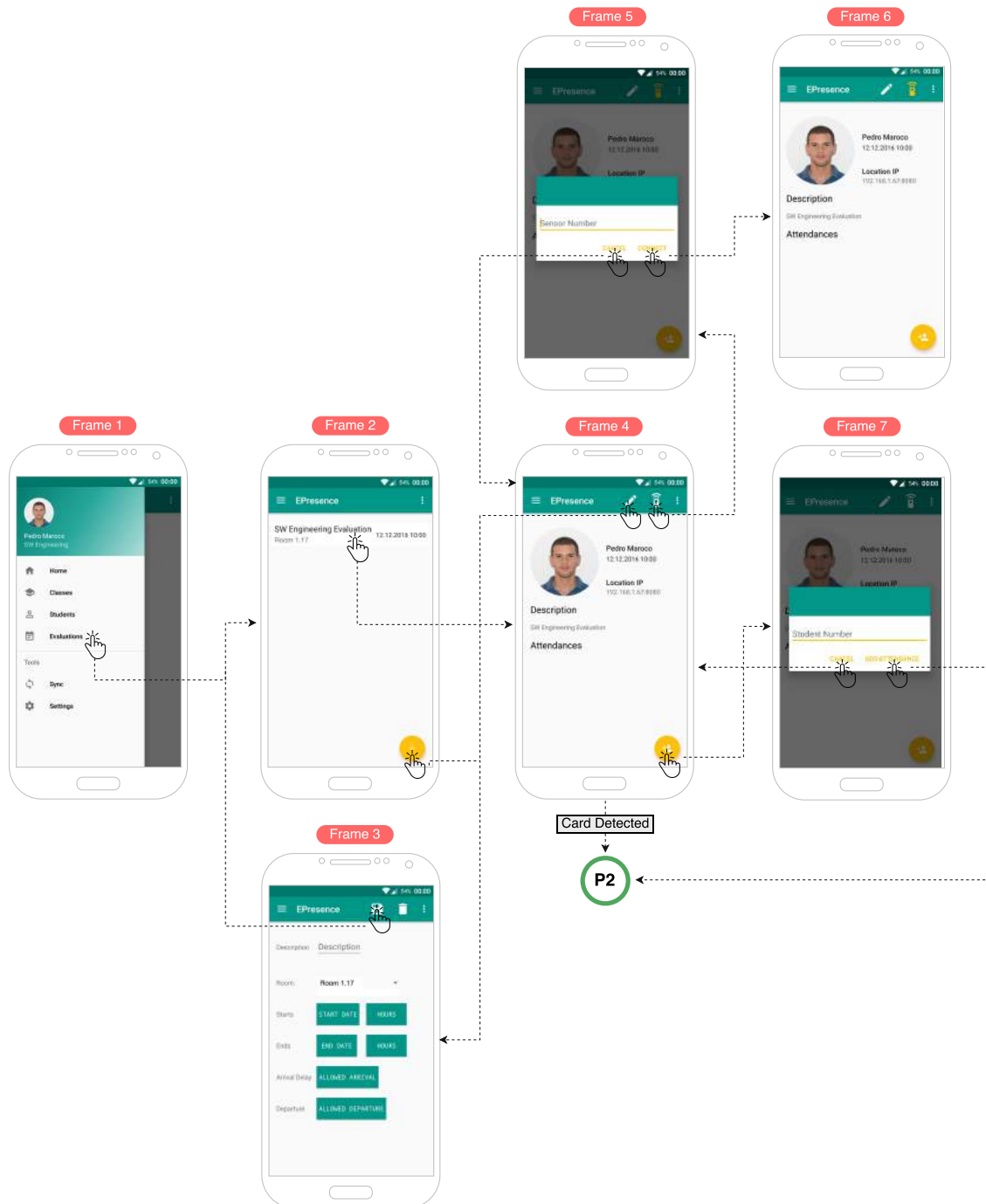
During this validation, the system will assign a random free seat for the student to do the evaluation activity. If there are no more free seats, an error message will be displayed and the student's attendance will not be registered.

If the student's presence has already been registered, the in-place validation is performed (Fig. 6.8(b): Frame 2). During this phase, the system begins by loading the student's data, such as the name, student number and assigned seat position to be displayed during visual confirmation by the faculty member. If the visual confirmation is accepted, the student's geographical position validation will begin. In order to perform this task, the application receives the position data from the [IPS](#) and verifies if the student is within a radius threshold established from the seat location assigned. If the received position is outside the radius or if the application is unable to communicate with the [IPS](#), an error message will be presented.

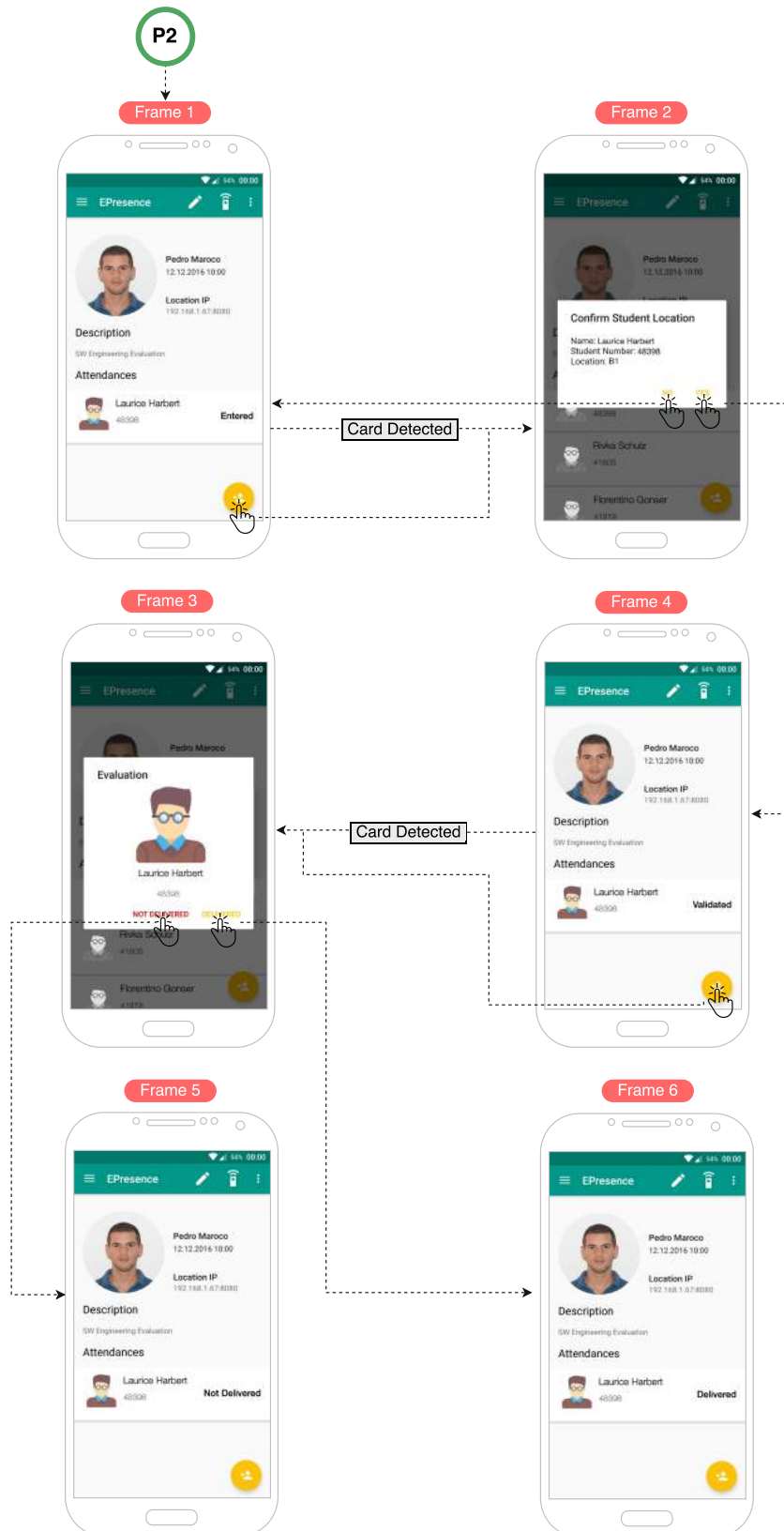
Finally, if the student's in-place validation was performed successfully, the system will carry out the delivery validation phase.

In this stage, the system will display the student's data, such as photo, name and student number, followed by the Delivered or Not Delivered options that should be selected appropriately regarding the answer's sheet (Fig. 6.8(b): Frame 3).

Likewise, the user can export the list of participants and validation status at any time by selecting the Export Attendances option in the evaluation detail menu.



(a) E-Presence App - Evaluation app flow - Part 1



(b) E-Presence App - Evaluation app flow - Part 2

Figure 6.8: E-Presence App - Evaluation app flow

6.2.2 E-Presence Database Model

This section describes in detail the data types in the application database and the relationship between them. The database model is presented in Fig. 6.9.

6.2.2.1 Students

Each student registered in the application is represented by an entry in the `students` table.

A student is represented by his/her full name, student number, card ID and photograph, which corresponds to `full_name`, `number`, and `card_id` attributes, respectively, defined using the TEXT datatype. The `card_id` attribute can be NULL if the student's card has not yet been registered in the app. The student's profile picture is automatically loaded from an image repository whose filename matches the student's number, which is a unique attribute in the table.

6.2.2.2 Teachers

Each teacher registered in the application is represented by an entry in the `teachers` table.

A teacher is represented by his/her full name, card ID, email and password, which corresponds to `full_name`, `card_id`, `email` and `password` attributes, respectively, defined using the TEXT datatype. The `email` and `password` attributes are required to login in the application.

Similarly, as explained in sub-subsection 6.2.2.1, the `card_id` attribute can be NULL if the teacher's card has not yet been registered in the app. Also, the teacher's profile picture is automatically loaded from an image repository whose filename matches the student's number, which is a unique attribute in the table.

6.2.2.3 Networks

Each entry in the `networks` table represents the authentication credentials required to pair a single card reader.

Each sensor is represented by an SSID, keyphrase and a number, which corresponds to `ssid`, `key` and `sensor_number` attributes. The `key` attribute can be NULL if a card reader does not require an authentication password.

6.2.2.4 Faculties

Each entry in the `faculties` table represents a single faculty institution.

The faculty entity is described by an institution name, which is represented by the `name` attribute, defined using the TEXT datatype.

6.2.2.5 Buildings

Each entry in the `buildings` table represents a single building inside a faculty institution.

The building entity is described by the building name, which is represented by the name attribute, defined using the TEXT datatype. Since a building belongs to a faculty, this entity also receives the primary key from the `faculty` entity, considering the relationship between the two entities is N:1.

6.2.2.6 Rooms

Each entry in the `rooms` table represents a single classroom inside a building.

The rooms entity is described by the rooms name, which is represented by the name attribute, defined using the TEXT datatype. Since a room belongs to a building, this entity also receives the primary key from the building entity, considering the relationship between the two entities is N:1.

6.2.2.7 Courses

Each course lectured in the faculty is represented by an entry in the `courses` table.

A course is represented by a course name, semester and year, which corresponds to name, semester and year attributes, respectively, defined using the TEXT datatype.

6.2.2.8 Turns

Each entry in the `turns` table represents a lecture turn from a specific course.

The turns entity is described by the turn label, which is represented by the `label` attribute, defined using the TEXT datatype. Since a turn belongs to a course, this entity also receives the primary key from the course entity, considering the relationship between the two entities is N:1. Since each turn has a responsible teacher, this entity also receives the primary key from the `teachers` entity, as a result of the N:1 relationship between the two entities.

6.2.2.9 Classes

Each class scheduled in the application is represented by an entry in the `classes` table.

The classes entity is described by a title, start date/time, end date/time, the max time allowed to enter the classroom regarding the start time and the minimum time allowed to leave the classroom after the class starts. The previous fields are represented by the `title`, `start_datetime`, `end_datetime`, `max_delay_arrival` and `min_time_departure` attributes, respectively. The `title` attribute was defined using the TEXT datatype and the remaining attributes were defined using the NUMERIC datatype.

Considering the relationship between the entities turns and rooms is N:1, this entity also receives the primary key from these entities. This relationship was established since a class is lectured for some turn in a specified classroom.

6.2.2.10 Classes Attendances

Each entry in the `class_attendance` table represents a single attendance from a student in a specific class.

The `class_evaluations` entity is described by an entrance and an exit timestamps. The previous fields are represented by the `entrance_timestamp` and `exit_timestamp` attributes, respectively. These attributes were defined using the `NUMERIC` datatype.

This entity also receives the primary key from the entities `students` and `classes` from the N:1 relationship formed by these entities, since the recorded attendance is of a student in a class.

6.2.2.11 Evaluations

Each evaluation scheduled in the application is represented by an entry in the `evaluations` table.

The `evaluations` entity is described by a description, start date/time, end date/time, the max time allowed to enter the classroom regarding the start time and the minimum time allowed to leave the classroom after the evaluation activity starts. The previous fields are represented by the `description`, `start_datetime`, `end_datetime`, `max_delay_arrival` and `min_time_departure` attributes, respectively. The `description` attribute was defined using the `TEXT` datatype and the remaining attributes were defined using the `NUMERIC` datatype.

Considering the relationship between the entities `courses` and `rooms` is N:1, this entity also receives the primary key from these entities. This relationship was established since an evaluation is carried out in a course and in a classroom.

6.2.2.12 Evaluation Attendances

Each entry in the `eval_attendance` table represents a single attendance from a student in a specific class.

The `class_evaluations` entity is described by an entrance and exit timestamps. The previous fields are represented by the `entrance_timestamp` and `exit_timestamp` attributes, respectively. These attributes were defined using the `NUMERIC` datatype.

This entity also receives the primary key from the entities `students` and `classes` from the N:1 relationship formed by these entities, since the registered attendance is of a student in an evaluation activity.

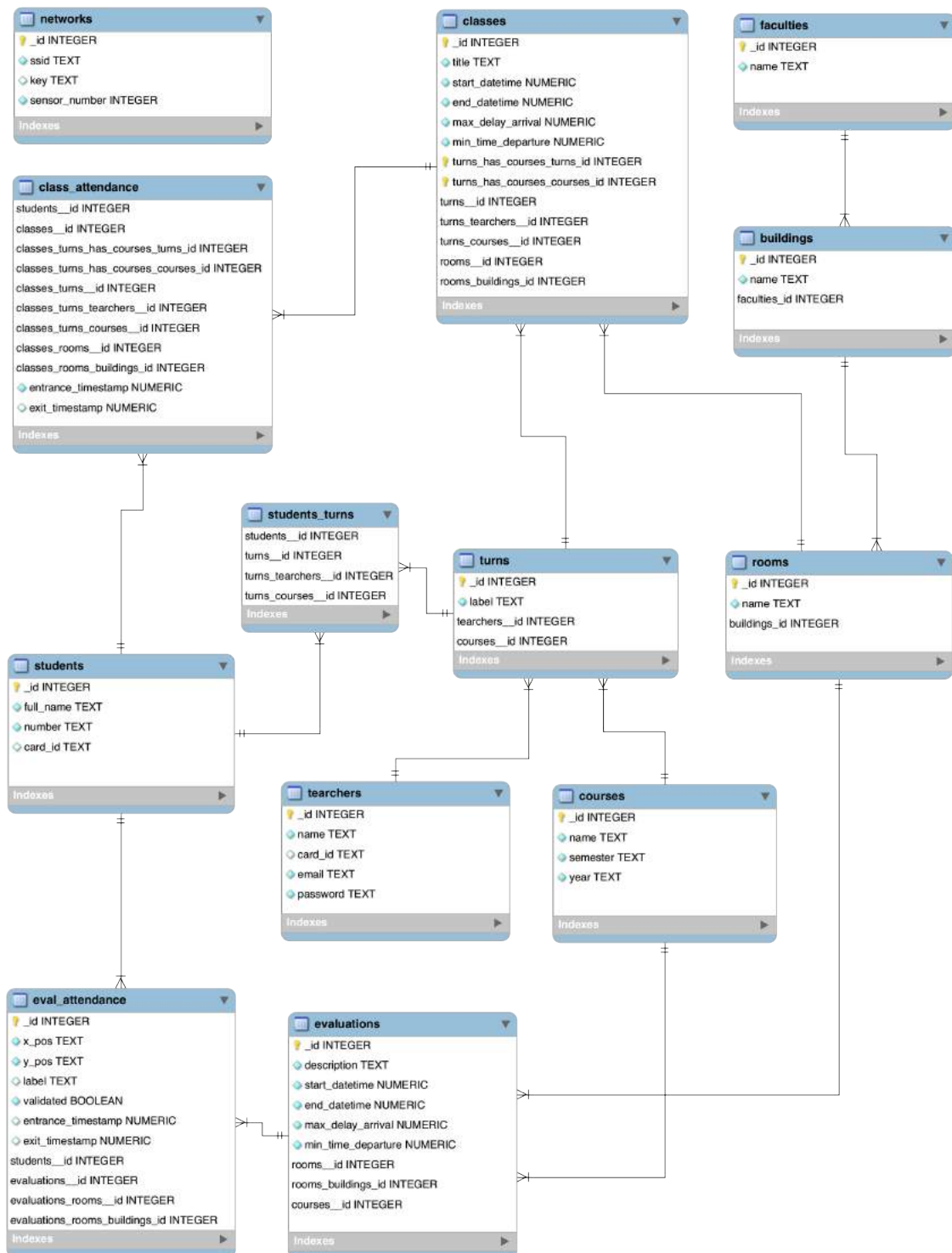


Figure 6.9: E-Presence App - Database model

6.2.3 Representation and Data Loading

In order to read the data and populate the application database, a representation convention was defined for each type of data, using JSON objects.

At the first use of the application the data is read and uploaded into the E-Presence database, however, the remaining updates must be done manually through the sync functionality. In order to facilitate changes in conventions of JSON files and to convert the JSON string objects to internal objects, several JSON parsers were developed for each different data types. Listings 6.1 and 6.2 represent examples of notations used to represent some data.

Listing 6.1: Example of a student entry in JSON notation

```
1 [
2   {
3     "full_name" : "Pedro Miguel Real Maroco",
4     "number"    : "41864",
5     "card_id"   : "D8A02E63"
6   }
7 ]
```

Listing 6.2: Example of a room entry in JSON notation

```
1 [
2   {
3     "building_id" : 1,
4     "label"       : "Room 1.17",
5     "tables": [
6       {"x":0.62,"y":2.18,"label":"A1"},
7       {"x":1.82,"y":2.18,"label":"A2"},
8       {"x":3.69,"y":2.18,"label":"A3"},
9       ...
10    ]
11  }
12 ]
```

6.3 Indoor Positioning System

Due to certain limitations detailed in section 7.1.2, an iOS application was developed to send the student location at the time of in-place validation to the E-Presence application (Fig. 6.10).

In order to send the position coordinates, a service was created in the Android application that creates an HTTP server to receive the IPS data. The connection between the IPS and the app is established through a TCP socket, using the IP address and the server port of the device running the application.

Each time the **IPS** updates the coordinate values, a new message is sent containing a JSON object with the updated position value. If the **IPS** service is disabled, the communication socket is closed.

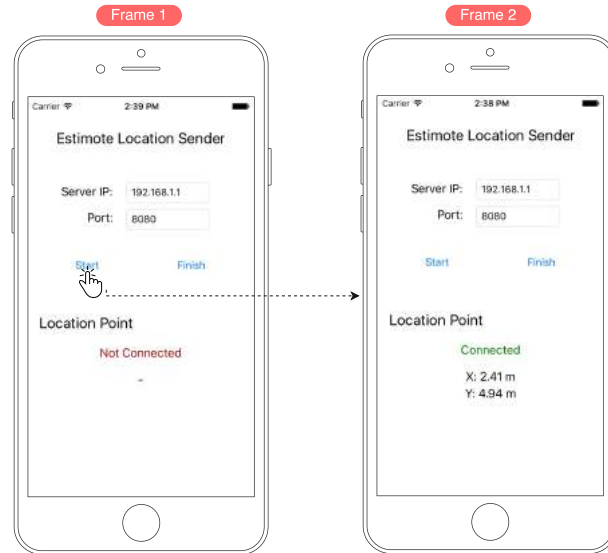


Figure 6.10: Indoor Position System - App flow

6.4 Card Reader

The card reader (Fig. 6.11) communicates with the application through a secure wireless AP that is set by the reader as soon as it starts operating. To pair the reader in the application, the user must enter the specific sensor number which, through the implemented logic, obtain the authentication credentials of the reader in the database.

Whenever a card is detected, the Unique ID (UID) from the NFC chip is read and sent to the application.



Figure 6.11: Card Reader System - Hardware setup

EVALUATION

This chapter contains a detailed analysis of the results obtained using the system developed in a real case study. It begins by describing the methodology used to perform the system's evaluation followed by a discussion and comparison of the performance results obtained.

7.1 Methodology

In order to define the main goal of this chapter, the template formulated in [Bas+01] has been followed: **Analyze** the behavior of the system developed **for the purpose of** evaluate **with respect to** the time performance of the system, **from the point of view of** researchers **in the context** of an experiment conducted using a real case scenario with participants from the Computer Science department of NOVA University (FCT/UNL).

7.1.1 Case Study Environment

The classroom used to perform the system evaluation, presented in Fig. 7.1, was equipped with 8 BLE beacons from *Estimote*, covering 39,85 m^2 of room area with an accuracy of +/- 1 meter [Syl15]. Each valid seat was identified with a label containing a row letter and a seat number. After the layout of the tables has been set, the coordinates of each valid seat was measured with the purpose of creating a simplified **Building Information Model (BIM)** of the room, using JSON notation to be loaded within the Android app. Fig. 7.2 presents the room setup used to conduct the evaluation activity.

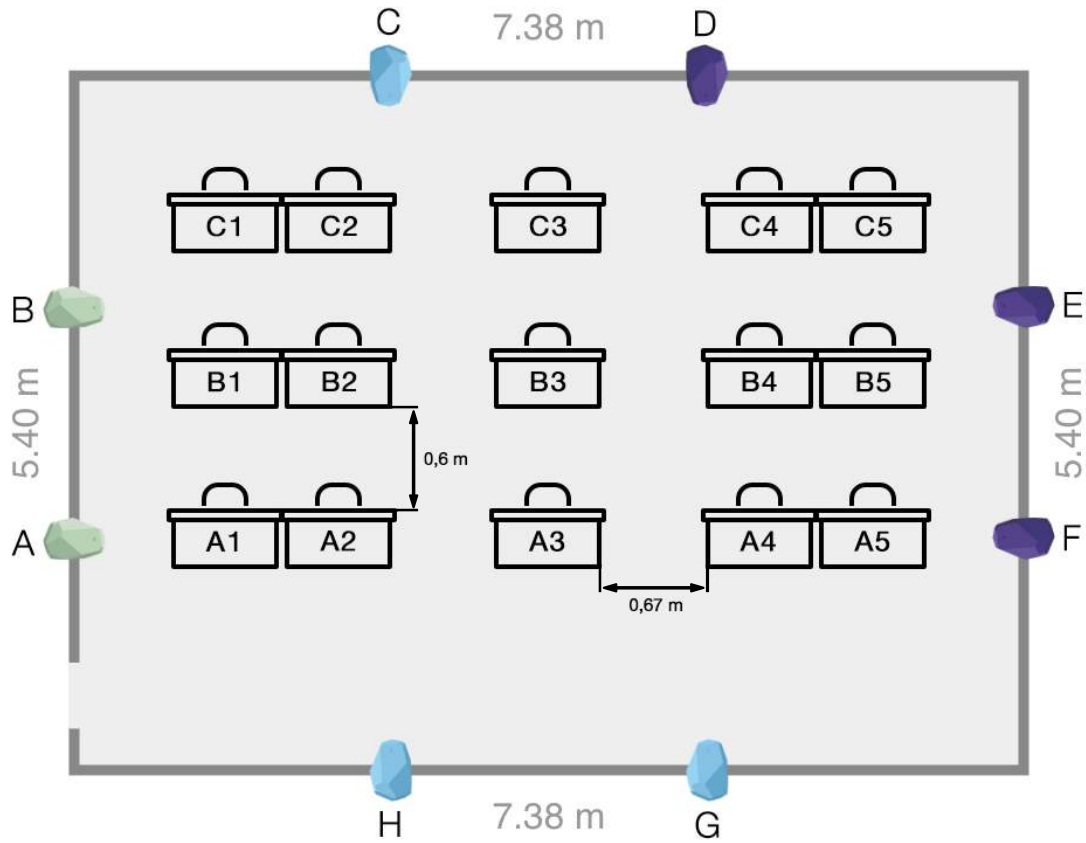


Figure 7.1: Scheme of classroom used to evaluate the system

7.1.2 Prototype Setup

The hardware used during the evaluation process was the following:

- **MIFARE Student Cards** - Containing MIFARE Classic chips [Mif];
- **Raspberry Pi 2 - Model B+ with NFC Reader** - Reader Identiv SCL3711 supporting the ISO/IEC 14443 Type A and NFC protocol [Ide16];
- **iOS Device** - iPhone 6 running iOS v9.2.1 (13D15);
- **Android Device** - OnePlus One running Android v6.0.1;
- **8 Estimote Proximity Beacons** - Hardware v3.3 running firmware A3.2.0 [Estb];

The use of different devices was due to the fact that the SDK provided by Estimote for the beacons used was targeted for iOS platforms at the moment of prototype development. Also, the Android device used was not compatible with the MIFARE chips used for the student cards.

However, this solution can be centralized in the future using an Android device with NFC reader compatible with the MIFARE protocol and an *IPS* capable of running in an Android environment.

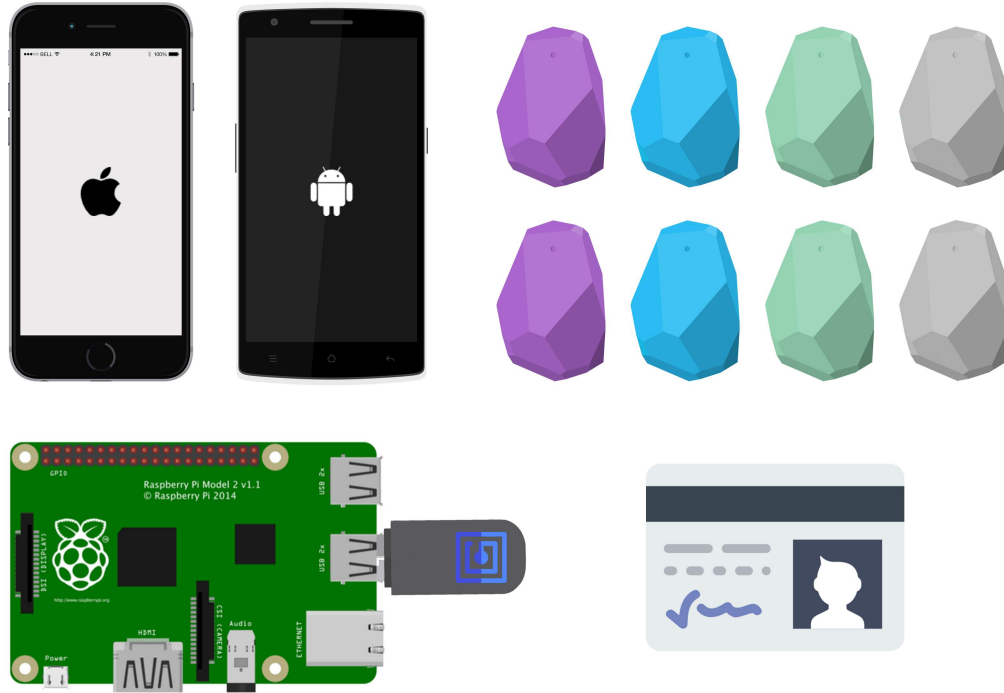


Figure 7.2: Hardware setup used for evaluating the system

7.1.3 Evaluation Performance

In order to perform the system evaluation, a group of 10 students was used during 3 different assessment activities to verify and validate the actual behavior against the expected behavior of the system.

Before starting the evaluation, it was first explained how the system operates in each phase of the evaluation activity. To guarantee the same conditions in the different samplings, each student was asked at the beginning of each activity to have his/her student card in hand.

After starting the activity, during the Entrance Validation phase, each student validated his student card at the entrance, then read the assigned seat and followed away. During this stage, the **Mean Service Rate** metric was measured based on the conditions imposed. This time metric was measured from the moment the student followed in order to validate his card until he/she left for the assigned location.

Later, during the In-Place Validation phase, the faculty member started by validating each row, proceeding to the next one after the previous row validation was completed. Here, the **Mean Service Rate** metric was measured from the moment the faculty member arrives next to a seat until he left for the next valid seat. To compare with the traditional method, a second In-Place validation was made. This time, after drawing the layout map of the classroom, the faculty member registered the information of each student card,

asking the student to validate and sign the recorded information.

Finally, during the Delivery Validation, each student delivers the evaluation's answer sheets and confirms their delivery by passing their student card through the NFC sensor. Additionally, the teacher validates the delivery of the evaluation sheets through the application. Then again, the **Mean Service Rate** metric was measured from the moment the student follows to validate his student card near the NFC reader until the faculty member validates the delivery through the application. For comparative purposes, the students were asked to deliver the evaluation's answer sheets again, but the validation was only completed as soon as the student signed a delivery evaluation sheet.

7.2 Results

This section intends to evaluate the performance of the system against the traditional method in each phase of the evaluation activity.

7.2.1 Entrance Validation

By analyzing the chart in Fig. 7.3, it can be concluded that there is a disadvantage of the E-Presence system when compared to the traditional method during the Entrance Validation phase. This delay occurs because the student has to validate his student card and will have to check the seat location assigned by the system to where it should be headed to.

In contrast to the traditional method, this delay does not occur since every student follows directly up into the classroom to a random row and seat position. For this reason, the entrance time was not considered using the traditional method.

However, if the student's enrollment in the evaluation activity is verified on a list of enrolled students, this process will be slower.

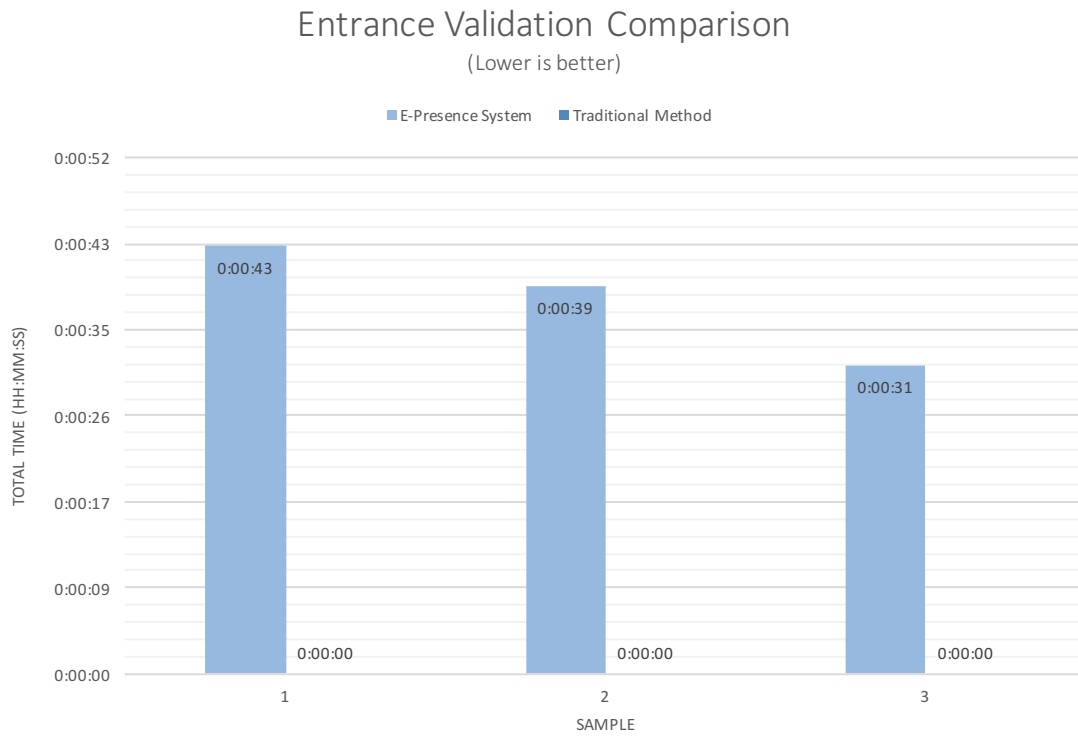


Figure 7.3: Time comparison results for Entrance Validation phase

7.2.2 In-Place Validation

Considering the chart in Fig. 7.4, it can be concluded that the E-Presence system has a much better performance than the traditional method during In-Place Validation phase.

Unlike the traditional method where the teacher has to copy the student's information manually to the right seat on the handmade map and the student has to verify that the information registered is correct, the developed system abstracts the interaction between the faculty member and the student, avoiding interruptions in the execution of the evaluation activity by the student. This is a time-consuming and error-prone process, particularly in situations where the evaluation activity environment is crowded. For this comparison was also not considered the time in which the faculty member is drawing the map of the classroom, that can be a difficult task to perform in a large classroom.

Another additional point is that the E-Presence system guarantees that the student is in fact on the assigned seat, since it uses the *IPS* to verify the geographical location at the moment of validation, ensuring fraud control.

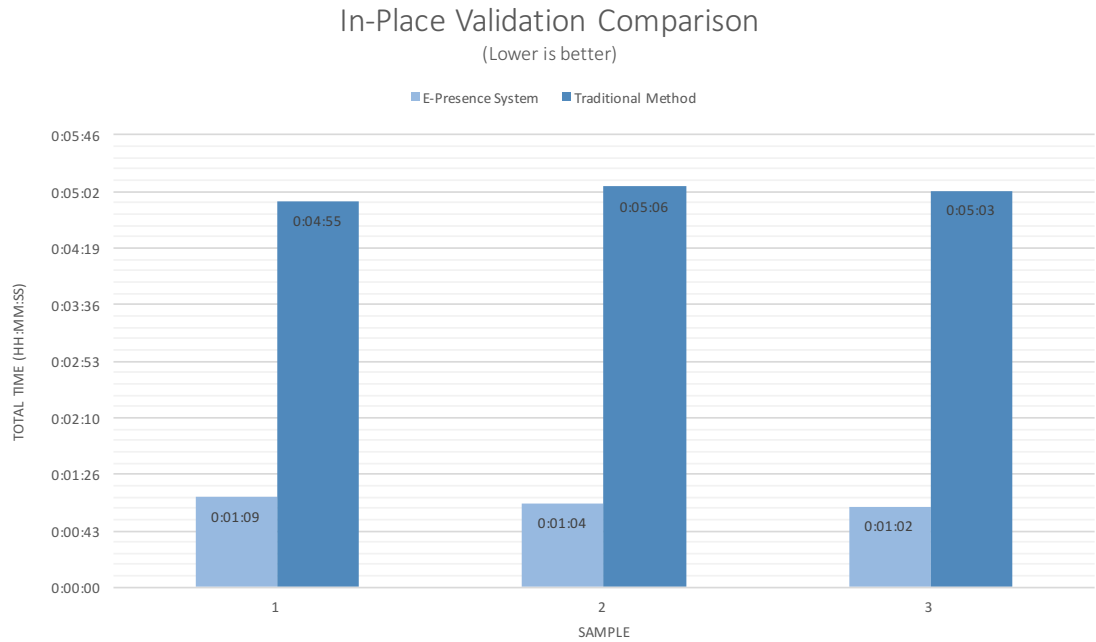


Figure 7.4: Time comparison results for In-Place Validation phase

7.2.3 Delivery Validation

As illustrated by the chart presented in Fig. 7.5, it can be concluded that the E-Presence system also has a better performance over the traditional method during Delivery Validation phase.

Similarly to the process using the traditional method and analyzed in subsection 7.2.2, the faculty member has to find on the handmade map the location of the student and proving their delivery. Also, another standard method of validating deliveries is by signing a delivery sheet. However, both methods are slower than using the E-Presence system.

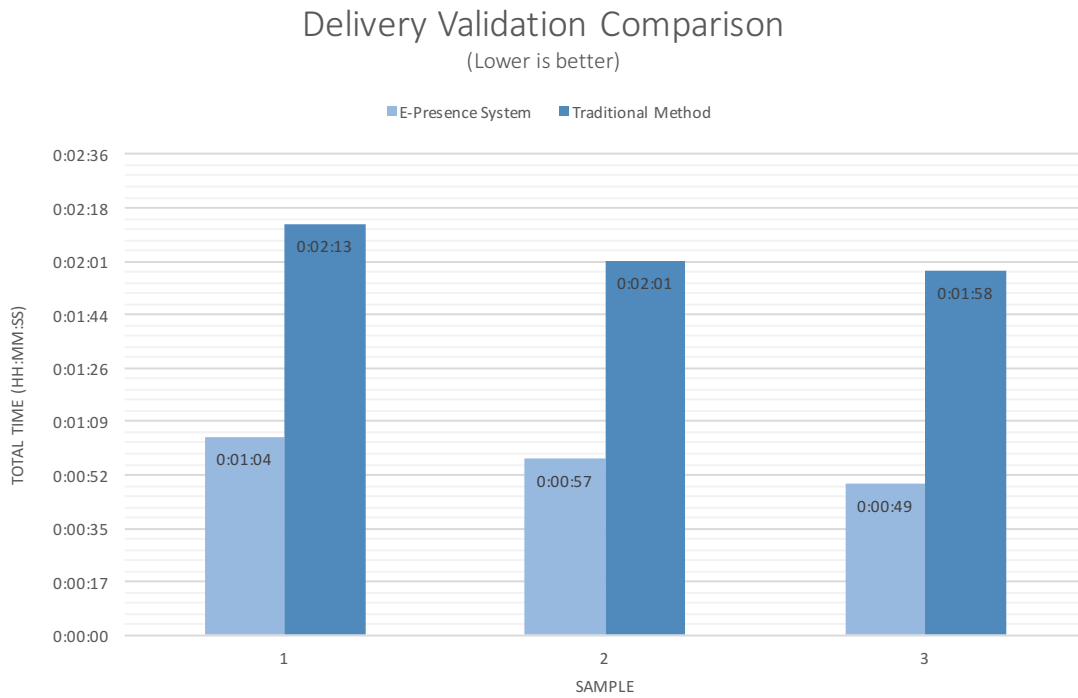


Figure 7.5: Time comparison results for Delivery Validation phase

7.2.4 System Overview

Although the developed system presents a below performance during the Entrance Validation phase, the overall performance during the evaluation activities is higher when compared to the traditional control method, as can be analyzed in the chart of Fig. 7.7. When compared to the traditional method, the E-Presence system shows a performance 2.7x higher, which represents 63% of time performance optimization.

Moreover, when the evaluation activity is finished, all information obtained during the activity is already in a digital format, leaving the task of uploading all the information in the management platform manually, as it is usually done when following traditional control methods by faculty members. The exported data can be easily configured to a different format, compatible with others faculty's information management platforms.

The usage of the system also allows a greater detail of control over each evaluation activity phases. This kind of information granularity can be useful for solving problems of suspected fraud or to optimize the performance of assessment activities. As an example, as demonstrated by the chart of Fig. 7.6, it can be seen that In-Place Validation is the phase that takes longer to perform when compared to the other phases. To optimize this phase, more than one system could be used at the same time to increase performance. This approach will be detailed in section 7.3.

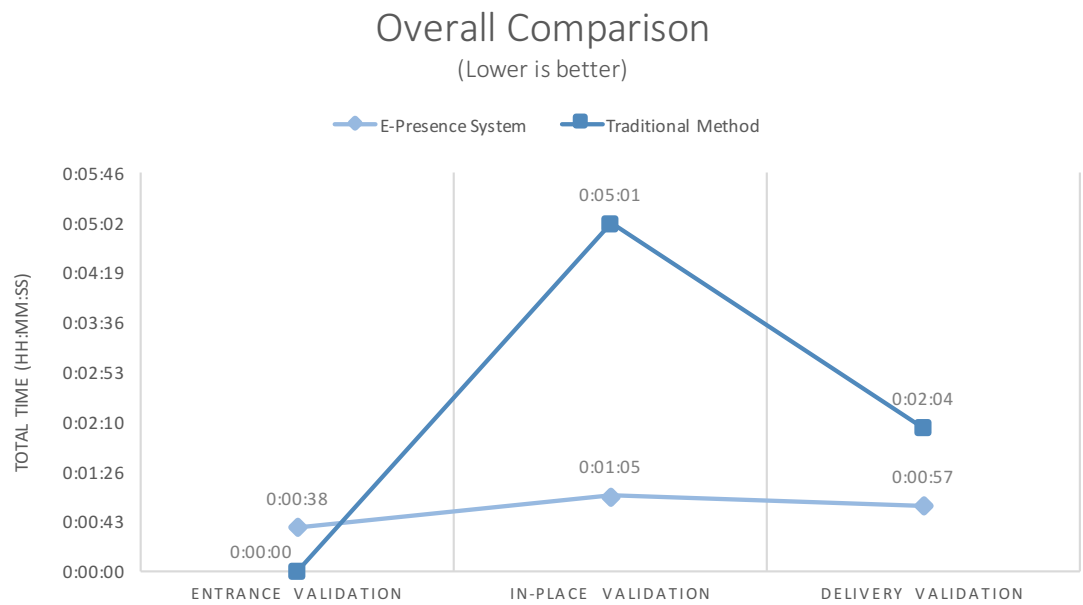


Figure 7.6: Time comparison results for overall performance

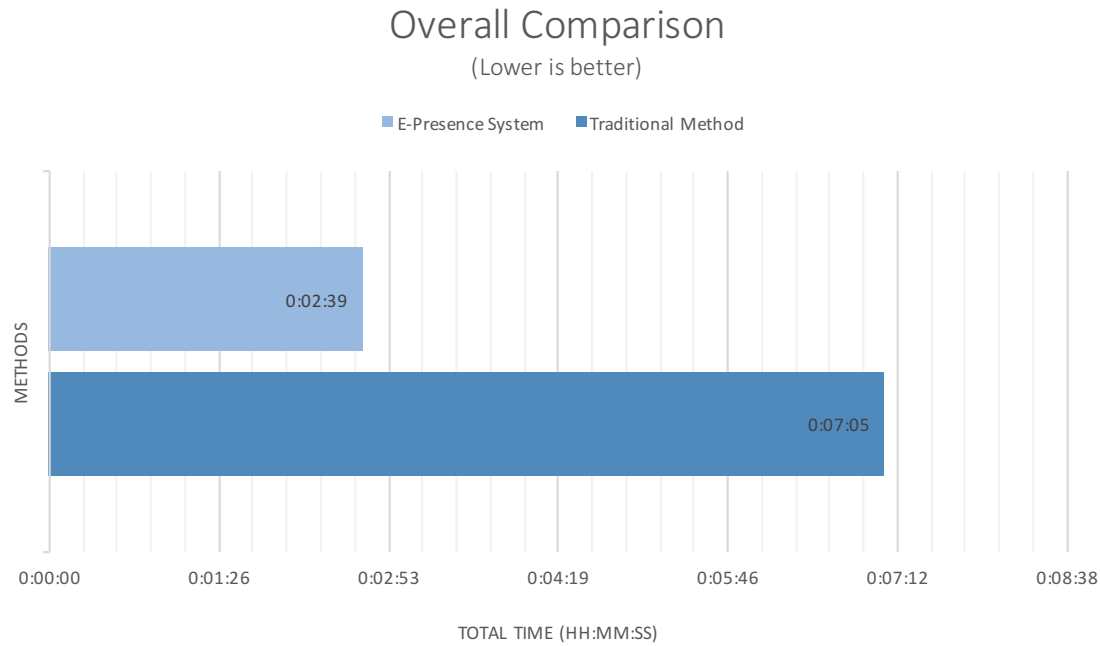


Figure 7.7: Total time comparison results of each system

7.3 System Behavior Simulation

Based on the Mean Service Rate metrics obtained during the system evaluation and explained in subsection 7.1.3, it is possible to define a set of mathematical expressions capable of simulating the operation of the system. As a result, we were able to estimate the service time of each phases using different parameters such as the number of available servers.

With regard to the research of Erlang [Erl09], this system can be modeled using the Waiting Line Theory, also known as Queuing Theory. This theory is a mathematical study of waiting lines which can be used to model and predict waiting times and the number of customer arrivals in a specific service [Sun09].

With the purpose of describing and classify the system's queue, Kendall's notation will be used [Ken53].

This notation is presented in the following form $A/S/C/K/D$, where [Hil12]:

- **A** – Denotes the time between arrivals to the queue;
- **S** – Denotes the time/size of the job;
- **C** – Denotes the number of servers at the node;
- **K** – Denotes the capacity of the queue;
- **D** – Denotes the queueing discipline.

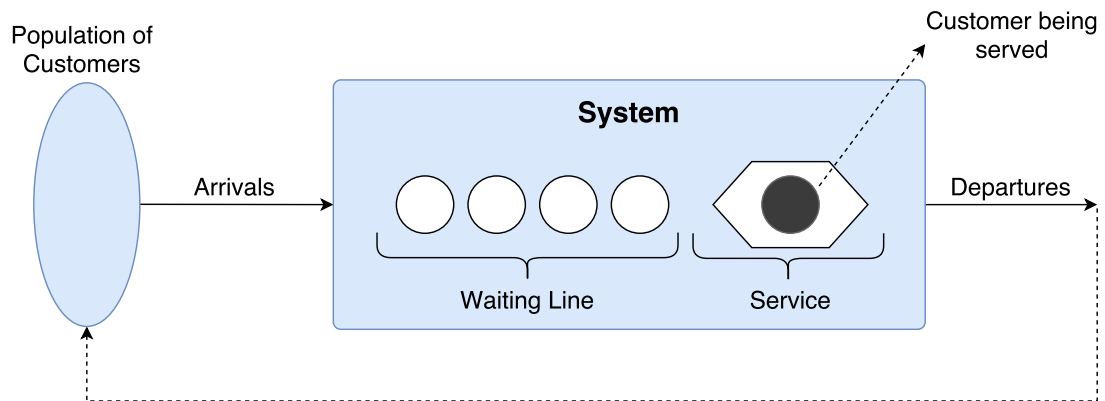


Figure 7.8: Structure of a waiting line system

7.3.1 Metrics Results

The metrics recorded in each of the phases and described in subsection 7.1.3 can be found in Tab. 7.1. The Mean Service Rate (μ) value was calculated based on the setup and the environment described in subsection 7.1.1.

Table 7.1: Definition of metrics recorded during the system evaluation

Validation Phase	S1	S2	S3	Total Avg. Time	Mean Service Rate (μ)
Entrance	0:00:43	0:00:39	0:00:31	0:00:38	0:00:04
In-Place	0:01:09	0:01:04	0:01:02	0:01:05	0:00:07
Delivery	0:02:13	0:02:01	0:01:58	0:00:57	0:00:06

7.3.2 Simulation Expressions

Regarding the notation presented in the beginning of chapter 7.3, the system developed is described as: **M/M/S/K/FCFS**¹.

The first parameter is denoted by the value **M**, since arrivals are processed using a Poisson distribution where arrival distributions times are random [Hil12]. This means time gap between successive arrivals cannot be predicted with certainty.

Likewise, the second parameter is denoted by the value **M**, since important variations in the length of the service may occur, such as a student who does not have his student card and must be manually validated in the system by the faculty member.

Moreover, the third parameter, denoted by the value **S**, varies according to the number of attendant servers available in each evaluation activity, with a minimum value of 1.

Next, the fourth parameter, denoted by the value **K**, is dependent on the number of participants or the capacity of available seats in the classroom where the evaluation activity is held. If the number of enrolled students is greater than the capacity of the room, **K** will have the value of available seats in the room, otherwise, **K** will have the value of the number of enrolled students in the evaluation activity.

Finally, the fifth parameter, it is often used the **FCFS**¹ queue discipline, where the first students to arrive at the room are the first to be served.

As explained by the author in [Per09], it can be concluded that the mathematical formulas required to calculate the average time of a student in the system (W_s) are the following:

$$\rho = \frac{\lambda}{S\mu} \quad (7.1)$$

¹FCFS: "First-Come, First-Served".

Where in equation 7.1:

- ρ – Represents the average utilization of the system;
- λ – Denotes the mean arrival rate of customers (average number of customers arriving per unit of time);
- S – Denotes the number of servers;
- μ – Denotes the mean service rate (average number of customers that can be served per unit of time).

$$P_0 = \begin{cases} \left[\sum_{n=0}^{S-1} \frac{(S\rho)^n}{n!} + \frac{(S\rho)^S}{S!} \left(\frac{1-\rho^{K-S+1}}{1-\rho} \right) \right]^{-1}, & \rho \neq 1 \\ \left[\sum_{n=0}^{S-1} \frac{S^n}{n!} + \frac{S^S}{S!} (K-S+1) \right]^{-1}, & \rho = 1 \end{cases} \quad (7.2)$$

Where in equation 7.2:

- P_0 – Represents the probability that no customers are in the service system at a given time.

$$W_s = \begin{cases} \frac{1}{\mu} + \frac{P_0 S^{S-1} \rho^S}{\mu(1-\rho)^2 (S! - S^S \rho^K P_0)} \times [1 - \rho^{K-S} (1 + (1-\rho)(K-S))], & \rho \neq 1 \\ \frac{S^{S-1} P_0 (K-S)(K-S+1)}{2\mu(S! - S P_0)} + \frac{1}{\mu}, & \rho = 1 \end{cases} \quad (7.3)$$

Where in equation 7.3:

- W_s – Represents the average time spent waiting in the system, including service.

As a result, the total average execution time of each of the phases can be calculated by the following expression:

$$Total_{W_s} = W_s K \quad (7.4)$$

Where in equation 7.4:

- $Total_{W_s}$ – Represents the total average execution time of a specific phase.

CONCLUSIONS

This chapter presents a summary of the work developed and presented in this dissertation. To conclude, suggestions for the future work are presented.

8.1 Summary

In this work, we identified a common problem in the diverse educational systems during the assessment activities and proposed, through a mobile and easily adaptable system, a solution capable of helping and assisting faculty members during these events.

Before starting the development of the system, we began by analyzing the traditional process method of assessment activities to identify the functionalities that the system must offer and the requirements that must be fulfilled.

With the purpose of studying previous works, modeling techniques, tools and technologies currently available to model and develop the proposed system, an SLR was performed. Afterwards, the results obtained were analyzed, and the technological choices and tools/techniques to be used to model and develop the system were further studied in detail.

After completing the phase of modeling the system and to test and validate the proposed solution, a prototype was implemented and tested in a real case scenario. This prototype was later used to evaluate the performance of the system against the traditional methods.

The evidence collected suggest that the developed system had a significant impact on the traditional method, which in addition to the performance obtained ensures a rigorous control and fraud prevention in the evaluation activity. In addition to a detailed record about each phase of the assessment activity, the work performed by the teacher during and after the activity is also reduced through this approach.

8.2 Future Work

As future work, we intend to develop a single multi-platform solution and reduce the cost of the system by using a single mobile device, capable of reading MIFARE/NFC cards and communicate with the [IPS](#) without resorting to other external devices.

It is also intended to develop the multi-server mode, which allows more than one device to control the same evaluation activity in different classrooms and create a management platform to facilitate the integration and communication of data between the faculty's information systems and our application.

Other features like path optimization during the beginning of the activity and control of environmental conditions such as noise and temperature for quality control of the activity environment will be implemented later.

BIBLIOGRAPHY

- [AA+14] M. A. Al-Ammar, S. Alhadhrami, A. Al-Salman, A. Alarifi, H. S. Al-Khalifa, A. Alnafessah, and M. Alsaleh. “Comparative survey of indoor positioning technologies, techniques, and algorithms”. In: *Proceedings - 2014 International Conference on Cyberworlds, CW 2014* (2014), pp. 245–252. doi: 10.1109/CW.2014.41. URL: <http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=6980768>.
- [Amb04] S. W. Ambler. *The object primer: Agile model-driven development with UML 2.0*. Cambridge University Press, 2004.
- [Ant14] P. Antsaklis. “Goals and challenges in cyber-physical systems research editorial of the editor in chief”. In: *IEEE Transactions on Automatic Control* 59.12 (2014), pp. 3117–3119.
- [App14] Apple Inc. *Getting Started with iBeacon*. 2014. URL: <https://developer.apple.com/ibeacon/Getting-Started-with-iBeacon.pdf>.
- [Bas+01] V. R. Basili, G. Caldiera, and H. D. Rombach. “Goal Question Metric Paradigm”. In: *Encyclopedia of Software Engineering* 1 (2001), pp. 528–532.
- [Bos] Bosch. *Safe braking with the Antilock Braking System (ABS)*. URL: http://products.bosch-mobility-solutions.com/media/en/ubk_europe/specials/abs/pdf_1/abs_brochure_de.pdf.
- [Dar+15] D. Dardari, P. Closas, and P. M. Djuri. “Indoor Tracking: Theory, Methods, and Technologies”. In: *IEEE Transactions on Vehicular Technology* 64.4 (2015), pp. 1263–1278.
- [Der+12a] P. Derler, E. Lee, A. S. Vincentelli, et al. “Modeling cyber-physical systems”. In: *Proceedings of the IEEE* 100.1 (2012), pp. 13–28.
- [Der+12b] P. Derler, E. A. Lee, and A. Sangiovanni Vincentelli. “Modeling cyber-physical systems”. In: *Proceedings of the IEEE* 100.1 (2012), pp. 13–28. ISSN: 00189219. doi: 10.1109/JPROC.2011.2160929.
- [Erl09] A. K. Erlang. “The theory of probabilities and telephone conversations”. In: *Nyt Tidsskrift for Matematik B* 20.33-39 (1909), p. 16.

- [FH15] R. Faragher and R. Harle. “Location fingerprinting with bluetooth low energy beacons”. In: *IEEE Journal on Selected Areas in Communications* 33.11 (2015), pp. 2418–2428. ISSN: 07338716. DOI: 10.1109/JSAC.2015.2430281. URL: [http://ieeexplore.ieee.org/ielx7/49/5594698/07103024.pdf?tp={\&}arnumber=7103024{\&}isnumber=5594698\\$\backslash\\$nhhttp://ieeexplore.ieee.org/xpl/articleDetails.jsp?tp={\&}arnumber=7103024{\&}ranges=2010{_}2015{_}p{_}Publication{_}Year{\&}queryText=bluetooth+beacon](http://ieeexplore.ieee.org/ielx7/49/5594698/07103024.pdf?tp={\&}arnumber=7103024{\&}isnumber=5594698\backslashnhhttp://ieeexplore.ieee.org/xpl/articleDetails.jsp?tp={\&}arnumber=7103024{\&}ranges=2010{_}2015{_}p{_}Publication{_}Year{\&}queryText=bluetooth+beacon).
- [Fri11] P. Fritzson. “Modelica A cyber-physical modeling language and the Open-Modelica environment”. In: *IWCMC 2011 - 7th International Wireless Communications and Mobile Computing Conference* (2011), pp. 1648–1653. DOI: 10.1109/IWCMC.2011.5982782.
- [Hil12] F. S. Hillier. *Introduction to operations research*. Tata McGraw-Hill Education, 2012.
- [Hu13] F. Hu. *Cyber-Physical Systems: Integrated Computing and Engineering Design*. CRC Press, 2013.
- [Ide16] Identiv. *SCL3711 Contactless USB Smart Card Reader*. 2016. URL: http://files.identiv.com/products/smart-card-readers/contactless/sc13711/SCL3711_Contactless_USB_Smart_Card_Reader_DS.pdf (visited on 01/2017).
- [JT10] H. Jaakkola and B. Thalheim. “Architecture-Driven Modelling Methodologies.” In: *EJC*. 2010, p. 2.
- [Jen+11] J. C. Jensen, D. H. Chang, and E. A. Lee. “A model-based design methodology for cyber-physical systems”. In: *Wireless Communications and Mobile Computing Conference (IWCMC), 2011 7th International*. IEEE. 2011, pp. 1666–1671.
- [Ji+15] M. Ji, J. Kim, J. Jeon, and Y. Cho. “Analysis of positioning accuracy corresponding to the number of BLE beacons in indoor positioning system”. In: *International Conference on Advanced Communication Technology, ICACT 2015-August* (2015), pp. 92–95. ISSN: 17389445. DOI: 10.1109/ICACT.2015.7224764. URL: <http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=7224764>.
- [JTC14] I. JTC. *Smart cities*. Tech. rep. 2014. URL: http://www.iso.org/iso/smart_cities_report-jtc1.pdf.
- [Kee07] S. Keele. “Guidelines for performing systematic literature reviews in software engineering”. In: *Technical report, Ver. 2.3 EBSE Technical Report*. EBSE. 2007.

- [Ken53] D. G. Kendall. "Stochastic processes occurring in the theory of queues and their analysis by the method of the imbedded Markov chain". In: *The Annals of Mathematical Statistics* (1953), pp. 338–354.
- [Kim+15] S. Kim, S. Ha, A. Saad, and J. Kim. "Indoor positioning system techniques and security". In: *e-Technologies and Networks for Development (ICeND), 2015 Forth International Conference on*. IEEE. 2015, pp. 1–4.
- [Kit+09] B. Kitchenham, O. Pearl Brereton, D. Budgen, M. Turner, J. Bailey, and S. Linkman. "Systematic literature reviews in software engineering - A systematic literature review". In: *Information and Software Technology* 51.1 (2009), pp. 7–15. ISSN: 09505849. DOI: [10.1016/j.infsof.2008.09.009](https://doi.org/10.1016/j.infsof.2008.09.009). URL: <http://dx.doi.org/10.1016/j.infsof.2008.09.009>.
- [Kjæ+10] M. B. Kjærgaard, H. Blunck, T. Godsk, T. Toftkjær, D. L. Christensen, and K. Grønbaek. "Indoor positioning using GPS revisited". In: *Pervasive Computing*. Springer, 2010, pp. 38–56.
- [Lar04] C. Larman. *Applying UML and Patterns: An Introduction to Object Oriented Analysis and Design and Iterative Development*. Third. Prentice Hall, 2004.
- [Lat+12] Z Lattmann, a Nagel, T Levendovszky, T. Bapty, S. Neema, and G. Karsai. "Component-based Modeling of Dynamic Systems using Heterogeneous Composition". In: *MPM workshop 2012* (2012), pp. 73–78. URL: http://www.researchgate.net/publication/233784309_Component-based_Modeling_of_Dynamic_Systems_using_Heterogeneous_Composition/file/d912f50b7a53caf40d.pdf.
- [Lee+08] E. Lee et al. "Cyber physical systems: Design challenges". In: *Object Oriented Real-Time Distributed Computing (ISORC), 2008 11th IEEE International Symposium on*. IEEE. 2008, pp. 363–369.
- [LS11] E. A. Lee and S. A. Seshia. *Introduction to embedded systems: A cyber-physical systems approach*. Second. Lee & Seshia, 2011. URL: eeseshia.org/releases/LeeSeshia_DigitalV2_0.pdf.
- [Lei+13] C. U. Lei, H. N. Liang, and K. L. Man. "Building a smart laboratory environment at a university via a cyber-physical system". In: *Proceedings of 2013 IEEE International Conference on Teaching, Assessment and Learning for Engineering, TALE 2013 August* (2013), pp. 243–247. DOI: [10.1109/TALE.2013.6654439](https://doi.org/10.1109/TALE.2013.6654439).
- [Liu+07] H. Liu, H. Darabi, P. Banerjee, and J. Liu. "Survey of wireless indoor positioning techniques and systems". In: *IEEE Transactions on Systems, Man and Cybernetics Part C: Applications and Reviews* 37.6 (2007), pp. 1067–1080. ISSN: 10946977. DOI: [10.1109/TSMCC.2007.905750](https://doi.org/10.1109/TSMCC.2007.905750). URL: http://ieeexplore.ieee.org/ielx5/5326/4343957/04343996.pdf?tp=*&arnumber=

- 4343996{\&}isnumber=4343957<http://ieeexplore.ieee.org/xpl/articleDetails.jsp?tp={\&}arnumber=4343996{\&}queryText=Survey+of+wireless+indoor+positioning+techniques+and+systems>.
- [Mar10] P. Marwedel. *Embedded system design: Embedded systems foundations of cyber-physical systems*. 2010, p. 1.
- [Nak+12] S. Nakajima, S. Furukawa, and Y. Ueda. “Co-analysis of SysML and simulink models for cyber-physical systems design”. In: *Proceedings - 18th IEEE International Conference on Embedded and Real-Time Computing Systems and Applications, RTCSA 2012 - 2nd Workshop on Cyber-Physical Systems, Networks, and Applications, CPSNA Figure 2* (2012), pp. 473–478. ISSN: 1533-2306. DOI: 10.1109/RTCSA.2012.22.
- [Par+10] C. J. J. Paredis, Y. Bernard, R. M. B. H.-p. D. Koning, and S. Friedenthal. “An Overview of the SysML-Modelica Transformation Specification”. In: *Jet Propulsion 2* (2010), p. 14. ISSN: 23345837. DOI: 10.1002/j.2334-5837.2010.tb01099.x. URL: http://www.omgwiki.org/OMGSysML/lib/exe/fetch.php?id=sysml-modelica:sysml{_}and{_}modelica{_}integration{\&}cache=cache{\&}media=sysml-modelica:incose{_}sysml-modelica{_}7-13-10.pdf.
- [Per09] C. R. V. Pereira. “Uma introdução às filas de espera”. PhD thesis. Universidade da Madeira, 2009.
- [PR08] M. Petticrew and H. Roberts. *Systematic reviews in the social sciences: A practical guide*. John Wiley & Sons, 2008.
- [Pop+07] A. Pop, D. Akhvlediani, and P. Fritzson. “Towards Unified System Modeling with the ModelicaML UML Profile”. In: *In Proceedings of the 1st International Workshop on EquationBased ObjectOriented Languages and Tools EOOLT’07* (2007), pp. 13–24. URL: <http://www.ep.liu.se/ecp/024/002/ecp2407002.pdf>.
- [Raj+10] R. Rajkumar, I. L. I. Lee, L. S. L. Sha, and J. Stankovic. “Cyber-physical systems: The next computing revolution”. In: *Design Automation Conference (DAC), 2010 47th ACM/IEEE* (2010), pp. 0–5.
- [Sch13] W. Schamai. *ModelicaML: Getting Started*. Tech. rep. Technical Report 1.8.3, EADS Innovation Works-Linköping University, 2013, pp. 1–23.
- [Sch+09] W. Schamai, P. Fritzson, C. Paredis, and A. Pop. “Towards Unified System Modeling and Simulation with ModelicaML: Modeling of Executable Behavior Using Graphical Notations”. In: *7th Modelica Convergence 0* (2009), pp. 0–9. DOI: 10.3384/ecp09430081. URL: <http://www.modelica.org/events/modelica2009/Proceedings/memorystick/pages/papers/0081/0081.pdf>.

- [Shi+11] J. Shi, J. Wan, H. Yan, and H. Suo. "A survey of cyber-physical systems". In: *Wireless Communications and Signal Processing (WCSP), 2011 International Conference on*. IEEE. 2011, pp. 1–6.
- [Som09] I Sommerville. *Software Engineering*. 9th ed. Addison-Wesley, 2009, p. 790. ISBN: 9780137035151.
- [Sun09] V. Sundarapandian. "7. Queueing Theory". In: *Probability, Statistics and Queueing Theory*. PHI Learning (2009).
- [Tan+12] Tang Junjie, Zhao Jianjun, Ding Jianwan, Chen Liping, Xie Gang, Gu Bin, and Yang Mengfei. "Cyber-physical systems modeling method based on Modelica". In: *2012 IEEE Sixth International Conference on Software Security and Reliability Companion* (2012), pp. 188–191. DOI: [10.1109/SERE-C.2012.49](https://doi.org/10.1109/SERE-C.2012.49). URL: <http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=6258468>.
- [Waw+15] F. Wawrzik, W. Chipman, J. M. Molina, and C. Grimm. "Modeling and simulation of Cyber-Physical Systems with SICYPHOS". In: *Proceedings - 2015 10th IEEE International Conference on Design and Technology of Integrated Systems in Nanoscale Era, DTIS 2015* (2015). DOI: [10.1109/DTIS.2015.7127375](https://doi.org/10.1109/DTIS.2015.7127375).

WEBOGRAPHY

- [Ble] *Bluetooth Low Energy*. URL: <https://www.bluetooth.com/what-is-bluetooth-technology/bluetooth-technology-basics/low-energy> (visited on 02/2016).
- [Bor15] W. Borowicz. *How precise are Estimote Beacons - Estimote Community Portal*. 2015. URL: <https://community.estimote.com/hc/en-us/articles/201302836-How-precise-are-Estimote-Beacons> (visited on 02/2016).
- [Del] *Education IT Solutions - Education Technology - EMC*. 2016. URL: <https://middle-east.emc.com/industry/public-sector/education-it.htm> (visited on 12/2016).
- [Esta] *Estimote Beacons*. URL: <http://estimote.com/> (visited on 02/2016).
- [Estb] *Estimote Beacons - Product Comparison*. URL: <http://estimote.com/products/> (visited on 11/2016).
- [Ibm] *IBM - Education technology solutions*. URL: <https://www-935.ibm.com/industries/education/> (visited on 12/2016).
- [Mif] *MIFARE Classic | NXP*. URL: http://www.nxp.com/products/identification-and-security/mifare-ics/mifare-classic:MC_41863 (visited on 11/2016).
- [Obj] *Objective C - Apple Developer*. 2014. URL: <https://developer.apple.com/library/mac/documentation/Cocoa/Conceptual/ProgrammingWithObjectiveC/Introduction/Introduction.html> (visited on 02/2016).
- [Omg] *OMG Systems Modeling Language*. URL: <http://www.omgsysml.org/> (visited on 02/2016).
- [Swi] *Swift - Apple Developer*. URL: <https://developer.apple.com/swift/> (visited on 02/2016).
- [Syl15] M. Syldatak. *Indoor location accuracy problem - Indoor Location - Estimote Community Forums*. 2015. URL: <https://forums.estimote.com/t/indoor-location-accuracy-problem/2710/3> (visited on 02/2016).

